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THORACIC SURGERY

ALTON OCHSNER, M.D., *Guest Editor*

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SYMPOSIUM ON THORACIC SURGERY

Foreword

Thoracic surgery is unique in that it is the oldest, yet most recently developed, of all surgical specialties. In addition to the difficulties encountered in all surgical specialties before the advent of anesthetics and asepsis, operations on the thorax were particularly hazardous because of the necessity of negative pressure within the thorax to maintain oxygen and carbon dioxide exchange and also because interference with the cardiovascular mechanism resulted in early deprivation of oxygen in vital structures, such as the heart, brain, spinal cord, and kidneys. In 1904, Sauerbruch, who could be designated the father of modern thoracic surgery, conceived the idea of the negative pressure chamber, after his chief, Geheimrat von Mikulicz, had unsuccessfully attempted esophageal resection in a dog, because intratracheal insufflation was ineffectual in maintaining oxygenation.



ALTON OCHSNER, M.D.

Half a century ago, thoracic surgery began to develop. About the same time collapse therapy in tuberculosis was introduced. Excisional therapy for pulmonary disease, both suppurative and tuberculous, was unsuccessful, however, until almost 30 years later. Development of thoracic surgery was greatly benefitted by introduction of antibiotics because the early thoracic operations were often complicated by infection, which either was fatal or caused permanent disability. Also, patients with suppurative disease could be properly prepared so that they could better tolerate the thoracic procedure.

Although Cutler in Boston and Allen and Graham in St. Louis attempted operations on the heart in the early 1920's, it was not until the 1940's that Blalock and Potts devised an operation for blue babies, Crawford and Gross corrected coarctation of the aorta, and Streider and Gross operated on patients with patent ductus arteriosus. Open cardiac surgery was made possible and safe because Gibbon was concerned about the high

mortality rate attending massive pulmonary embolism. To prolong oxygenation sufficiently for pulmonary embolectomy to be done safely, he conceived the idea of extracorporeal oxygenation, although before cardiopulmonary bypass was used in this way, it was successfully employed in open cardiac surgery. No field of medicine has been as spectacular and has made such great strides as has cardiovascular surgery, even though the eminent Austrian surgeon, Billroth, in 1883, predicted "The surgeon who would attempt to suture a wound of the heart would lose the respect of his colleagues."

The type of thoracic surgical procedures performed has greatly changed during the past quarter of a century. Pulmonary abscess, empyema, and bronchiectasis are uncommon today because they usually resulted from progressive infection before the availability of antibiotics. Even treatment of tuberculosis has changed. Collapse therapy, prevalent 30 years ago, has almost disappeared. Excisional therapy, although still valuable, is less frequently necessary. All of these changes, together with the feasibility of correcting both congenital and acquired cardiovascular anomalies, represent advances. Tragic, however, is the tremendous and unnecessary increase in incidence of the new, devastating pulmonary disease, bronchogenic carcinoma. Extremely rare and involving both sexes equally until 30 years ago, it has become the most common of all visceral cancers. The two great tragedies concerning this disease are, first, with the exception of the rare adenocarcinoma, bronchogenic cancer is preventable, and second, the curability rate is extremely low—approximately 60 per cent. Whereas antibiotics and surgical procedures have been effective in the treatment of other thoracic lesions, prevention is our only hope in combating this tremendous killer.

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History of Thoracic Surgery

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"And the Lord God caused a deep sleep to fall upon Adam, and he slept: and he took one of his ribs, and closed up the flesh instead thereof:

"And the rib, the Lord God had taken from man, made he a woman, and brought her unto the man." Book of Genesis, Chapter II, verses 21 and 22.

Thus, the first surgical operation ever performed was a thoracic one. Despite this early beginning it has been only in the last half century that real advances have been made in thoracic surgery. It is true that Hippocrates⁸⁸ apparently was able to differentiate between pneumococcic and streptococcic infections of the pleura, which Graham⁷¹ later differentiated scientifically, because in his book of Prognostics, Hippocrates wrote, "In cases of empyema treated by the cautery or incision, when the matter is pure, white, and not fetid, the patient recovers; and if of a bloody and dirty character, he dies."

Cardiac Wounds

Ambroise Paré,¹⁵⁰ the great French surgeon who lived from 1510 to 1590, observed in patients who had been injured that cardiac wounds healed spontaneously, and Jean Riolan,¹⁵³ an Italian surgeon, advocated trephining through the sternum to relieve pressure within the pericardium after pericardial injury. Willis¹⁹⁹ of Great Britain suggested drainage of a tuberculous cavity in 1664, and LeClerc,¹¹⁷ a Frenchman, suggested drainage of an empyema cavity in 1750. In 1843, Trousseau,¹⁸⁸ another Frenchman, popularized drainage of the pleural cavity for empyema, and in 1882, the Italian surgeon, Forlanini,⁶² advocated pneumothorax for the treatment of tuberculosis. Murphy¹³⁶ here in the United States in 1898 practiced the latter procedure.

Just 85 years ago, Billroth,²² the great Austrian surgeon, who did the first resection of the stomach for cancer, and who usually had remarkable vision, stated, "The surgeon who would attempt to suture a wound of the

heart would lose the respect of his colleagues." Cappelen,³³ on September 4, 1895, sutured a 2-cm. left ventricular stab wound in a 24-year-old man, who died 2½ days later of anemia and infection. In 1896, Rehn¹⁵⁵ of Germany successfully sutured a wound in a human heart, and in 1900, Hill^{86, 87} of Alabama, the father of Senator Lister Hill, did the first successful suture of the heart in the Western Hemisphere.

Pulmonary Embolism

In 1856 Virchow,¹⁹⁶ the great German pathologist, first described pulmonary embolism and reproduced the condition experimentally. In 1908, Trendelenburg,¹⁸⁷ a great German surgeon, described the technique of embolectomy because he had noted that most patients with pulmonary embolism did not die immediately after onset of the embolism. Although the Trendelenburg operation of pulmonary embolectomy had been tried many times in German clinics, it was not until 1924 that Kirschner,¹⁰⁶ a former pupil of Trendelenburg, performed the first successful pulmonary embolectomy. When the case was presented at a meeting of the German Surgical Congress in Berlin, which I attended, the audience was electrified by the report. After presentation of Kirschner's successful case, it became the custom in German clinics to place a Trendelenburg set in the room of any patient who had had a nonfatal infarction and in whom fatal infarction was likely, so that if massive embolism occurred, operation could be immediately performed in the patient's room. A constant vigil was maintained. Nyström,¹⁴⁴ who served as Visiting Professor of Surgery at Tulane in 1933, even advocated waiting until death seemed imminent before attempting the operation. How much better it would have been if they had done what we subsequently learned—prevented pulmonary embolization by ligating the vein on the cardiac side of the thrombus to prevent detachment of the thrombus and its entrance into the heart and lungs. In fact, Rosenstein,¹⁶² in 1917, advocated not only venous ligation but also thrombectomy to prevent pulmonary embolism. He stated that John Hunter had advocated proximal compression of a thrombosed vein to prevent embolism. At the turn of the century Trendelenburg had ligated both hypogastrics and spermatics. In 1932 DeBakey and I¹⁴⁵ advocated inferior vena caval ligation, and two years later Homans⁹¹ advocated proximal ligation of the femoral vein to prevent embolism.

In 1932, Gibbon and co-workers⁶⁹ collected 140 cases of attempted pulmonary embolectomies, with only 9 successes. Because of these poor results, he conceived the idea of extracorporeal oxygenation in patients with pulmonary embolism, to prolong their lives sufficiently to permit embolectomy. In 1934, he and his future wife, Maly, developed the extracorporeal oxygenation machine. In 1961 Allison and associates⁹ successfully performed pulmonary embolectomy using hypothermia.

Although the extracorporeal oxygenation apparatus was developed as a result of an idea that Gibbon had after watching a patient die of pulmonary

embolism at the Massachusetts General Hospital in 1931, he originally used it in 1953 to repair an atrial septal defect in a young woman, and it was not until 1961 that Sharp¹⁶⁹ and Cooley and associates⁴¹ successfully performed pulmonary embolectomy, using the cardiopulmonary bypass. Since then, it has been used often.

Tuberculosis

Surgical treatment of tuberculosis has undergone definite changes since 1820, when James Carson,³⁵ a British physician, suggested use of artificial pneumothorax in its treatment in order to put the lung at rest. He stated, "It has long been my opinion that if this disease [tuberculosis] is to be cured, and it is an advent of which I am by no means disposed in all cases to despair, it must be accomplished by mechanical means; or in other words, by surgical operation." Attempts were made by a surgeon under Carson's direction, but they were unsuccessful because there was no pleural space. Peronny¹⁵¹ stated that Gilchrist suggested pneumothorax before Carson had practiced it.

Jacobaeus⁹⁹ of Stockholm, in 1923, advocated closed intrapleural pneumolysis, which prevented collapse of the lung, in patients with adhesions between the visceral and parietal layers of the pleura.

In patients in whom artificial pneumothorax could not be performed, Stuertz¹⁸¹ of Germany advocated phrenic nerve paralysis. In 1913, Sauerbruch¹⁶⁵ reported good results after the phrenic nerve operation in 5 patients with tuberculosis. In 1922 Goetze⁷⁰ of Germany advocated radical phrenicectomy rather than avulsion of the nerve because of the danger of hemorrhage when the nerve was avulsed.

In 1885, de Cereville³⁶ of Switzerland reported resection of portions of the second and third, or more, ribs in 4 patients with apical tuberculosis. Six years later, Tuffier¹⁹⁰ of France advocated apical pneumolysis in addition to thoracoplasty. In 1907, Friedrich⁶⁵ of Germany, at the suggestion of the internist, Brauer, resected all ribs with their periosteum from the second through the ninth. Because the periosteum was removed, a flail chest developed, and of the first 7 patients operated on, 3 died. Two years later, Brauer suggested a two-stage operation to prevent the flail chest, subperiosteal resection to permit regeneration of the ribs, and resection of the first rib. In 1909, Freeman⁶⁴ of Denver did the first thoracoplasty in the United States.

Biondi²³ of Italy, in 1882, made extensive laboratory experiments demonstrating the feasibility of pulmonary resection, and suggested its use in treatment of tuberculosis. Block²⁹ of Germany reported extensive experimentation with pulmonary resection and, in 1883, resected the apices of both lungs in his own cousin, who died shortly after the operation. Because the cousin was found not to have tuberculosis at necropsy, Block killed himself.

Tuffier,¹⁸⁹ a French surgeon, in 1891 performed the first successful

resection of the apex of the lung for tuberculosis. Two years later Doyen⁵² of France successfully performed partial lobectomy for tuberculosis in a patient 10 years old. In the same year, Macewen¹²⁷ of Glasgow removed almost a whole lung for chronic tuberculosis in a patient who remained well for 45 years.

Excisional therapy in tuberculosis is still valuable, but with the introduction of antituberculosis agents, such as streptomycin, para-aminosalicylic acid, and isoniazid, tuberculosis has become much less prevalent than formerly. Previously performed procedures, such as phrenicectomy, artificial pneumothorax, and thoracoplasty, are almost never performed today.

Empyema

Empyema, which 30 years ago was an extremely serious condition, is now almost nonexistent. In 1927, when I came to the Tulane University School of Medicine as Professor of Surgery, the most frequent thoracic operations done were drainage of empyema and pulmonary abscesses. Chronic empyema plagued the thoracic surgeon. In 1879, Estlander⁵³ of Germany suggested thoracoplasty for chronic empyema in order to collapse the cavity. In 1892, Dolorme^{50a} of France and, in 1893, Beck²⁰ of Chicago advocated decortication of the lung for this condition.

During the first World War, the death rate from empyema was extremely high. The overall mortality rate was 30 per cent, and in some army camps it was as high as 70 per cent. Graham,⁷¹ by extensive experimental work, showed that the danger of open drainage during the pneumonic stage of the process (synpneumonic empyema) before the mediastinum became fixed resulted in mediastinal flutter and a high death rate. They listed three principles of treatment of acute empyema: (1) drainage with careful avoidance of an open hemithorax during the period of acute empyema, (2) early sterilization and obliteration of the cavity, and (3) maintenance of nutrition of the patient. They were the first to emphasize the importance of nutrition in chronic suppuration and its effect on recovery.

Pulmonary Abscess

Until the introduction of antibiotics, pulmonary abscess was common and followed pneumonic processes as well as aspiration. In 1899, Fraenkel⁶³ of Germany stated that 7.5 per cent of all influenzal pneumonias ended in pulmonary gangrene. There was a great deal of controversy in the 1920's about the role of embolization and aspiration in the production of pulmonary abscess. In 1926, Holman and associates⁹⁰ produced pulmonary abscesses experimentally with septic emboli. Holman showed the value of lobectomy experimentally. One year later, Smith¹⁷³ produced pulmonary abscess experimentally by injecting into the trachea material from the alveolar border of persons with pyorrhea. In this way, the role of aspiration in the production of pulmonary abscess was emphasized. In 1929, Lambert

and Weeks¹¹⁴ emphasized the role of anaerobic organisms in the production of pulmonary abscess. Neuhoff and Touroff,¹⁴¹ in 1936, advocated two-stage drainage of putrid or fetid abscesses. Drainage accomplished evacuation and aerobiosis.

Drainage of pulmonary abscesses, although it evacuated the pus, usually resulted in a chronic draining sinus with persistent suppuration, bronchial fistula, and chronic invalidism. In 1947, Kent¹⁰³ advocated pulmonary resection, which was a great advance. Pulmonary abscess is a rapidly disappearing disease, first because of effective therapy of pneumonitis with antibiotics and, second, because of prevention of aspiration.

Bronchiectasis

Another rapidly disappearing disease is bronchiectasis. In 1899, Krause¹¹⁰ in Germany did partial lobectomy for bronchiectasis, with recovery of the patient. The mortality rate, however, was extremely high. In 1914, Meyer¹⁸¹ of New York reported a 50 per cent mortality rate in 16 patients with bronchiectasis treated by pneumonectomy. In 1922, Sicard and Forestier¹⁷² of France described the technique of bronchography with iodized oil. This made possible visualization of the extent of the disease. The same year, Lilienthal¹²⁰ of New York reported a 42 per cent mortality rate in 14 lobectomies for bronchiectasis. He estimated that in selected cases a survival rate of 50 to 60 per cent could be expected, with restoration to health in nearly all. He used mass ligation.

Robinson,¹⁶⁰ in 1917, reported only one death among 5 patients with lower lobe bronchiectasis treated by resection. In his presidential address before the American Association of Thoracic Surgeons in 1923, he stated, "It has long been my belief that the greatest triumph in thoracic surgery will be the surgical eradication of this deplorable disease [bronchiectasis]. The enthusiast returned from the war, who has often dragged a lung lobe into a spread thoracic wound, opened it, scraped it, washed it, yea even removed it and concluded, therefrom, that thoracic surgery is freed of its supposed dangers and that the possibilities therein are comparable to those in the abdomen, let him attempt the same performance in his home hospital in the case of lower lobe bronchiectasis. Then he will learn what real thoracic pathology means." He then described the real difficulty encountered in operating on patients with bronchiectasis but added, "Nevertheless, we have obtained cures. Four years ago, the mortality rate was 50 per cent. It is less now. Progress has been made and will continue to be made."

In 1923, Graham⁷² collected 48 cases of resection for bronchiectasis with a 52 per cent mortality rate and complete success in 17. He reported 3 of his own cases with only one survival, the deaths being due to infection. Because of the high mortality rate after pulmonary infection, Graham conceived the idea of evacuating the pus-filled bronchi and establishing drainage by destroying the peripheral portions of the involved lobes with an actual cautery (cautery pneumonectomy). In 1925, he⁷³ reported a

mortality rate of 20 per cent in 20 patients with pulmonary suppuration treated by cautery pneumonectomy. Six were cured; 4 were asymptomatic but had bronchial fistulas, 3 were improved, and one could not be traced.

In 1931, Nissen¹⁴³ in Sauerbruch's Clinic performed total pneumonectomy on a 12-year-old girl for bronchiectasis, using mass ligation of the hilum. The same year, Churchill³⁷ of Boston, unaware that Davies⁴⁶ had used individual ligation and lobectomy for carcinoma in 1912, did a lobectomy for bronchiectasis, using individual ligation, but the patient died one week later of empyema. In 1932 Haight⁸¹ performed left total pneumonectomy for bronchiectasis using mass ligation. In 1937, however, Churchill^{37a} reported 84 cases of bronchiectasis treated by lobectomy, with a mortality rate of only 4.6 per cent and only 1.5 per cent for the 66 unilateral cases. In 1940, Blades and Kent²⁵ described the technique of individual ligation of hilar structures, which had been used by Davies⁴⁶ first in 1912 and again by Churchill³⁷ in 1931. Bronchiectasis has almost completely disappeared because acute parenchymal pulmonary infections, especially in children, are treated with antibiotics before destructive change in the in the bronchi occurs.

Bronchogenic Carcinoma

Although the incidence of inflammatory processes in the thorax, such as bronchiectasis, pulmonary abscess, and empyema, have definitely diminished, one pulmonary disease, bronchogenic carcinoma, is increasing greatly in incidence. Until 1935, neoplasms of the lung were extremely rare and affected men and women with equal frequency. In 1912, Adler⁵ was able to collect only 211 cases of cancer of the lung reported before 1900. Operations for malignant lesions of the lung were done largely for rare tumors, such as sarcoma. In 1884, Krönlein¹¹¹ of Zurich resected a recurrent sarcoma of the chest wall together with the involved portion of the lung in an 18-year-old girl, who was well after two years. In 1910, Kümmel¹¹³ of Germany did a pneumonectomy for carcinoma, using mass ligation, but the patient lived only six days. In 1912, Davies⁴⁶ of England performed lobectomy for carcinoma, using individual ligation of the hilar structures with success. He stated, "Cancer of the lung is in some of its early stages now accessible to surgical intervention and complete removal, but until this fact is more fully recognized and all pulmonary cases are subjected to routine radiologic examination, the growths will not be recognized until they have extended beyond the possibility of all treatment. In all doubtful cases, at least an exploratory thoracotomy should be undertaken." (Such a prophetic statement!) Unfortunately, his patient died from empyema on the eighth postoperative day.

In 1920, Sauerbruch¹⁶⁵ of Germany reported 2 cases of partial resection of the lung for carcinoma. In 1933, Churchill³⁸ of Boston successfully removed the lower and middle lobes of the right lung for carcinoma. On April 5, 1933, Graham⁷⁴ performed the first successful total pneumonectomy for

carcinoma on a physician, using mass ligation followed by thoracoplasty. The patient lived many years and, in fact, outlived Dr. Graham. The same year, on July 24 and November 3, Rienhoff,¹⁵⁷ using the anterior approach and individual ligation, did 2 pneumonectomies for carcinoma.

I performed my first pneumonectomy for malignant disease on April 15, 1936; the patient is living without evidence of recurrence. This was the tenth successful pneumonectomy for malignant disease. In 1950, Allison⁸ of England proposed radical pneumonectomy and, in 1958, Churchill and associates³⁹ proposed conservative resection of the lung, such as lobectomy or segmental pneumonectomy. For many years, I believed that more patients would be cured by radical excision (pneumonectomy and *en bloc* resection of mediastinal lymph nodes). I subsequently learned, however, that bronchogenic carcinoma is early angio-invasive and that systemic involvement is frequent and early, and that conservative resection is as beneficial as radical resection.

Esophageal Stricture

Stricture of the esophagus, which never was a common disease, is less common today than formerly, because with better warning methods ingestion of corrosive agents is less likely. In 1801, Vareliaud¹⁹³ of Paris reported treating a patient with esophageal stricture by means of silver catheter. In 1893, Abbé of New York used a string to saw through a stricture, employing cervical esophagotomy and gastrostomy. In 1901, Dunham,⁵⁴ using as a guide a string in the esophagus brought out through a gastrostomy, dilated an esophageal stricture by passing bougies through it. Wullstein²⁰⁰ of Germany, in 1904, advocated extrathoracic mobilization of a jejunal loop which was anastomosed to the cervical esophagus experimentally. The next year Beck¹⁶ of Chicago made a tube of the greater curvature of the stomach and anastomosed this to the esophagus after resection. The same year Roux¹⁶⁴ of Switzerland anastomosed a loop of jejunum, brought up under the skin of the thorax, to the stomach distally in a girl; the cervical anastomosis was not completed until four years later. Also in 1905, Lexer¹¹⁹ of Germany suggested making a tube from the skin of the anterior thorax, which had been used by Bircher in 1894 for carcinoma of the esophagus. This was used to bridge the gap between the cervical esophagus and the jejunal loop. In 1934, Owens and I¹⁴⁸ performed the first successful anterothoracic esophagoplasty in the United States. In 1949, Rapant and Hromada¹⁵⁴ of Czechoslovakia brought the stomach up through the thorax and anastomosed it to the esophagus in the upper thorax.

Carcinoma of the Esophagus

Esophageal carcinoma, although relatively rare in the United States, is common in Switzerland and Japan. In 1871, Billroth,²¹ the great Austrian surgeon, predicted that carcinoma of the esophagus could be resected because he erroneously believed that malignant lesions of the esophagus did

not metastasize via the lymphatics. In 1898, Rehn¹⁵⁶ of Germany first attempted intrathoracic resection of the esophagus, followed by esophageal anastomosis. In 1905, Beck¹⁶ of Chicago constructed a tube from the greater curvature of the stomach which was long enough to bring up into the chest, and in 1909, Green and Janeway⁷⁵ in the United States described a technique of mobilizing the stomach which was brought up into the thorax and anastomosed with the esophagus after the distal segment had been removed. One patient on whom this was done, however, died after 54 hours.

In 1913, Denk⁵¹ of Austria, working with two teams, one operating through an abdominal incision and the other through a cervical one, mobilized the esophagus; working from both ends using a ring stripper similar to that used in the treatment of varicose veins, he removed the esophagus. However, Torek¹⁸⁵ of New York, in 1913, first successfully removed the thoracic esophagus in a 67-year-old woman with a subaortic carcinoma. He had previously performed gastrostomy. At the time of the thoracotomy, the lower esophagus was resected, the esophagus was brought out through a cervical incision, and the distal esophagus with the carcinoma was removed. The remaining proximal segment of the esophagus was attached to the skin. A rubber tube was used to connect between the esophagostomy and the gastrostomy. The patient died of pneumonia 13 years later.

In 1923, while serving as an exchange surgical resident at the Kantons-spital in Zurich, I assisted Professor Clairmont in many cases of esophageal resection, using Denk's original technique. Unfortunately, many cases of tension pneumothorax developed and the operation was not very successful. In 1938, Adams and Phemister⁴ of Chicago resected the lower portion of the esophagus and upper portion of the stomach, mobilizing the distal end of the stomach and anastomosing the greater pouch with the esophagus. In 1941, DeBakey and I⁴⁷ collected 195 reported cases of esophageal resections and reported 4 of our own, in which the procedure of Adams and Phemister was used. In 1953, Yüdin²⁰¹ of Russia reported several hundred esophagectomies, in which a jejunal loop was used to bridge the gap. The next year, Sweet¹⁸² reported 450 cases of carcinoma of the esophagus, in 103 of which resection had been done. In 1957, Nakayama¹⁴⁰ of Japan reported 739 resections of the esophagus with a 3.9 per cent mortality rate.

Cardiac Resuscitation

In 1850, Hoffa and Ludwig⁸⁹ of Germany demonstrated that electrical stimulation to the mammalian heart caused fibrillation. On April 14, 1865, in Washington Leale¹¹⁶ was able to keep President Lincoln alive for one hour by applying external cardiac massage and mouth-to-mouth respiration to him after he had been shot. In 1874, Schiff and Hoche¹⁶⁷ of Germany resuscitated animals with cardiac arrest caused by chloroform anesthesia by cardiac massage and artificial respiration. Niehaus¹⁴² in the late 1880's was the first to employ cardiac massage in a human. The 40-year-old man

was operated on with use of chloroform anesthesia for a large goiter. Shortly after the operation began, the patient became cyanotic and respiration ceased. Almost immediately the pulse became imperceptible. Artificial respiration was begun without result. Professor Niehaus opened the chest and massaged the heart without success, apparently because of fibrillation ("seine Muskulture bot seitzweise ein leichtes Flimmern"—its musculature from time to time had a slight twitching).

In 1898, Tuffier and Hallion¹⁹² of France successfully resuscitated human beings with cardiac arrest by cardiac massage. In 1899, Prévost and Battelli¹⁵³ of France showed that myocardial twitching was the greatest hindrance to successful massage and the longer the interval between the arrest and the beginning of massage, the greater likelihood of myocardial twitching. In 1901 Ingelsrud⁹⁸ of Norway performed successful cardiac resuscitation on a patient in whom cardiac arrest followed completion of a hysterectomy. Artificial respiration was first used for 3 to 4 minutes, following which the thorax was opened and cardiac massage was performed. After approximately one minute cardiac pulsation returned but was weak. Massage was continued with complete recovery of the patient. In 1904, Crile⁴⁴ of Cleveland successfully applied external massage to a patient with cardiac arrest. One year later, D'Halluin of France termed myocardial twitchings fibrillations (tremulations fibrillaires).

In 1909, White¹⁹⁷ of the United States stated, "The heart stops from respiratory failure, entailing insufficient oxygen, low blood pressure, and the action of chloroform directly on heart muscles." Among 48 collected cases and 2 of his own, 9 recoveries occurred after cardiac massage. Fifteen more survivals for from one hour to several days occurred. In 1929, Hooker⁹² in the United States, studying experimental ventricular fibrillation caused by electric shock, discovered that it could be stopped by intracarotid injection of weak solutions of potassium chloride, combined with cardiac massage. He stated that ventricular fibrillation is believed to be the most common cause of death in electrical accidents. In 1933, Hooker and associates⁹³ were able to stop ventricular fibrillation in animals with electric shock. In 1936, Wiggers¹⁹⁸ of Cleveland applied 60-cycle alternating current to stop fibrillation in animals. The same year, Ferris and associates⁶⁰ successfully defibrillated the ventricles in sheep through the intact chest wall with alternating currents of 25 amperes.

In 1947, Beck and associates¹⁹ of Cleveland reported the first successful defibrillation of the human heart by electrical shock, and in 1951, Guyton and Satterfield⁸⁰ of Mississippi demonstrated the value of large electrodes because they promote "the greatest density of current flow at the lowest possible voltage. Small electrodes require several times as much voltage as do larger electrodes to achieve the same results." In 1951, Kouwenhoven and associates¹⁰⁸ developed closed chest defibrillation using alternating current, and in 1960, they¹⁰⁹ developed the technique of closed cardiac massage used clinically.

Coarctation of the Heart

In 1761, Morgagni¹³³ of Italy first described the anomaly, coarctation, which he had observed at necropsy on a monk. In 1839, Mercier¹³⁰ of France suggested the name coarctation when it is found in the region of the ductus arteriosus. In 1942, Blalock and Park²⁷ relieved experimentally produced coarctation by left subclavian and aortic anastomosis. In 1944, Crafoord⁴³ of Stockholm performed the first resection of coarctation with reanastomosis. He had conceived the technique when operating on a patient with ductus arteriosus in whom accidental tearing of the aortic end of the ductus necessitated cross-clamping of the aorta for 28 minutes. In 1945, Gross⁷⁶ of Boston did extensive experimental work on coarctation and the next year reported 8 cases of successful resection in human beings.^{76a} In 1949, Gross and associates^{76b} demonstrated the feasibility of homografts to bridge the gap in coarctation when the defect is too large to permit reanastomosis.

Patent Ductus Arteriosus

In 1907, Munro¹³⁵ of Boston, in addressing the Philadelphia Academy of Medicine on ligation of the patent ductus arteriosus, pleaded, "That I may be allowed to bring the suggestion for a new operation before your Society . . . on the basis that it has not been hastily conceived. On the contrary, long ago I demonstrated this technical possibility in the cadaver of newborn children and felt that it was justifiable on the living. At various times, I have tried to inspire the pediatric specialist with my views, but in vain. Now, in view of the recent advances in cardiac surgery for much of which we are indebted to the surgeons of this city, I will venture to place my ideas before you, asking that you do not dismiss them hastily." In 1937, Strieder¹⁸⁰ of Boston attempted ligation in a patient with patent ductus arteriosus and severe bacterial endocarditis, referred to him by Reginald Fitz. Because of the severe inflammatory process, ligation was not possible but he introduced several sutures, and although some improvement resulted, the patient died on the fourth postoperative day.

On October 26, 1939, Gross⁷⁸ of Boston successfully ligated a patent ductus arteriosus with No. 8 braided silk in a 7½-year-old girl. Subsequently, in a number of cases the ductus was ligated with umbilical tape, but because they were unsuccessful, the suggestion was made that all, if possible, should be divided and sutured. In 1940, Touroff and Vessel^{186a} of New York successfully ligated a patent ductus arteriosus for subacute bacterial endocarditis.

Congenital Heart Disease

In 1913, Doyen⁵³ of France inserted a tenotome through the right ventricle to divide a stenotic pulmonary valve in a child who died two hours later. In 1938, Blalock,²⁶ while at Vanderbilt University, experimentally anastomosed the left subclavian to the left pulmonary artery to study pulmonary hypertension, and four years later, with Park he²⁷ performed left

subclavian aortic anastomosis on a patient with coarctation. The case was presented at Johns Hopkins Hospital, at which time Helen Taussig inquired whether an operation could not be done to relieve cyanosis in pulmonary stenosis. On November 29, 1944, Blalock²⁸ successfully accomplished subclavian pulmonary anastomosis in a patient with tetralogy of Fallot. In 1946, Potts and associates¹⁵² in Chicago performed aortic pulmonary anastomosis, which Potts had conceived as he observed patients with patent ductus arteriosus who did fairly well until closure of the ductus.

On December 4, 1947, Sellors¹⁶⁸ of Great Britain divided the stenotic pulmonary valve in a patient with pure pulmonary stenosis. In 1948, Lord Brock⁸¹ of Great Britain stressed the importance of stenotic pulmonary valve in infundibular stenosis and advocated correction of both, which he did in February, 1948, by inserting a tenotome through the ventricular wall and incising the stenotic valve, followed by dilation with dilating forceps. The same year Murray¹³⁷ of Canada closed an atrial septal defect by closed blind suture technique, and two years later S ndergaard¹⁷⁵ of Sweden used a circumclulsion suture for the same purpose.

In 1952, Bailey¹² performed atriopexy to close an atrial septal defect. The same year Lewis and associates¹¹⁸ used hypothermia to close an auricular septal defect under direct vision. In 1953, Gross and Watkins⁷⁹ used the atrial wall to close an atrial septal defect, and in the same year Gibbon⁶⁸ of Philadelphia first used extracorporeal circulation to repair an atrial septal defect. In 1955, Lillehei and associates¹²² first closed a ventricular septal defect using extracorporeal circulation. In the same year, they¹²³ were the first to perform total correction of tetralogy of Fallot. These investigators, together with Mustard and co-workers,^{138, 139} Cooley and associates,^{41, 42} Kirklin and co-workers,^{104, 105} and Gerbode,⁶⁶ pioneered in the surgical correction of congenital heart defects.

Mitral Valve Disease

In 1902, Brunton³² wrote, "Mitral stenosis is not only one of the most distressing forms of cardiac disease, but in its severe forms, it resists all treatment by medicine. On looking at the contracted mitral orifice in a severe case of this disease, one is impressed by the hopelessness of ever finding a remedy which will enable the auricle to drive the blood in sufficient stream through the small mitral orifice, and the wish unconsciously arises that one could divide the constriction as easily during life, as one can after death." Twenty years later Allen and Graham,⁷ in St. Louis, devised a cardioscope to visualize the mitral valve, with which they did considerable experimental work. They observed that the incised mitral valve did not heal. They attempted three different operations on one patient, but without success.

In 1923, Cutler and Levine⁴⁵ of Boston, after considerable experimental work using a valvulotome, inserted through the apex of the left ventricle, divided a stenotic mitral valve. The patient lived 4½ years with little

change in her condition, however. On May 6, 1925, Souttar¹⁷⁷ of London operated on a 19-year-old girl with mitral stenosis by inserting the finger through the auricular appendage and digitally dilating the valve, which was not very stenotic. The patient was greatly improved. Souttar believed that the method of digital exploration through the auricular appendage could not be surpassed for simplicity and directness. He stated, "Not only is the mitral orifice directly at hand, but the aortic valve itself is almost certainly within reach through the mitral orifice. Owing to the simplicity of the structures and, oddly enough, to their constant and regular movement, the information given by the finger is exceedingly clear, and personally I felt an appreciation of mechanical realities of stenosis and regurgitation, which I never before possessed."

In 1945, Bailey¹¹ operated on a patient intending to "bite out" a piece of the mitral valve, but the patient died from a tear in the auricle. The next year, he operated on another patient with the idea of cutting the valve, but performed digital dilation instead; the patient died one day later, but the valvular release was found to be successful at necropsy. Smithy and Parker,¹⁷⁴ using a valvulotome and both auricular and ventricular approaches, operated on 7 patients with successful results in 5, indeed a great advance. They preferred the ventricular approach. On June 10, 1948, Bailey¹² performed his first successful commissurotomy with the valvulotome, and the same year Harken⁸³ reported results in treatment of mitral stenosis with the valvulotome. He subsequently became a great advocate of the finger fracture but Bailey continued to use the valvulotome.

In 1957, Lillehei and associates¹²³ were the first to use extracorporeal circulation to repair a mitral valve, as well as other cardiac procedures including annuloplasty, insertion of sleeve leaflets with or without chorda tendinae and placement of prosthetic baffles. Lillehei, Kay and associates,^{100, 101} Ellis and co-workers,^{56, 57} and Braunwald and Morrow³⁰ replaced the mitral valve with various prostheses with satisfactory early results, but late failures.

In 1958, Logan and Turner¹²⁴ of Great Britain introduced a transventricular dilator maneuver which greatly improved commissurotomy and is used today. It has been popularized in this country by Cooley and co-workers^{41, 42} and Gerbode.⁶⁶ In 1960, Starr¹⁷⁸ of Portland replaced a mitral valve with a ball and cage prosthesis and later reported a series of successful cases. Since then, several thousand prostheses have been successfully developed. Other mitral prostheses have been devised.^{15a, 70a, 127a, 172a} Large series of valvular replacements have been reported by the Baylor group, the Minneapolis group, Mayo Clinic, and the Cleveland Clinic.

Aortic Valvular Disease

Tuffier,¹⁹⁰ in 1912, relieved aortic valve stenosis by invaginating with the finger the aortic wall through the aortic valve; this maneuver resulted in a decrease in thrill which was previously felt. In 1914, Carrel and

Tuffier³⁴ demonstrated experimentally that the pulmonary artery and the aorta could be safely occluded for $2\frac{1}{2}$ to 3 minutes. They predicted that some day surgeons would be able to cauterize valvular lesions or repair them as was done at that time in experimental operations. In 1947, Smithy and Parker¹⁷⁴ experimentally lacerated the aortic valve through a transventricular approach. In 1950, Bailey¹⁴ experimentally dilated the aortic valve and operated on one patient, who died. He subsequently developed a mechanical dilator. In 1951, Hufnagel⁹⁵ used a plastic ball valve in the descending aorta in aortic insufficiency, and in 1954, he⁹⁷ reported results in 23 patients, 18 whom were well. In 1954, Clowes,⁴⁰ using the pump oxygenator, exposed the aortic valve directly to relieve stenosis, but the patient died.

In 1956, Lillehei and associates^{121, 122} were the first to treat aortic valvular disease by direct visualization, using extracorporeal circulation. Bahnson and associates,^{177a} Muller and associates,¹³⁴ and Hufnagel and co-workers^{95, 96} employed prosthetic leaflets to replace part or all of the diseased valve. In 1962, Harken⁸⁴ was the first to perform aortic valve replacement with caged ball valve in the subcoronary position. In 1962, Ross¹⁶³ of London and Barratt-Boyes^{15b} of New Zealand reported encouraging results with subcoronary replacement of homographs in the aortic area.

Coronary Artery Disease

In 1880, Langer¹¹⁵ of Germany demonstrated collaterals between the coronary arteries and the vessels of the pericardium and diaphragm. He stated that the extracardiac coronary anastomoses made it possible to feed the heart collaterally after obstruction of the main coronary branch. In 1903, Thorel¹⁸⁴ of Germany described the postmortem observations in a patient who had died of cancer; he found old adhesive pericarditis side by side with complete, longstanding obliteration of the mainstems of both left and right coronary arteries. He stated that for a long time the myocardium must have obtained its supply from the collateral circulation.

In 1921, Gross and Blum⁷⁷ of Boston demonstrated anastomoses between the coronary vessels and the parietal pericardial vessels. In 1929, Forssmann⁶¹ of Germany catheterized his own heart. In 1932, Hudson and co-workers⁹⁴ of Cleveland, by postmortem injection of the coronary arteries, found extracardiac anastomoses in 4 patients with pericardial adhesions. Subsequently, they did extensive experiments on production of pericardial adhesions.

Beck¹⁷ of Cleveland, on February 18, 1935, after considerable experimental work, attached the left pectoral muscle to the myocardium, after removal of the pericardium. In September, he reported 4 cases of patients on whom he had experimented. One died postoperatively of thrombosis of the aortic bifurcation; the others were benefitted. In 1936, O'Shaughnessy¹⁴⁹ of England, unaware of Beck's work, reported use of omentum to produce collateral adhesions, which he first performed in 1933. Unfortunately, O'Shaughnessy was killed at Dunkirk.

In 1941, Fauteaux⁵⁹ of Canada advocated ligation of the coronary sinus in angina pectoris. The first patient was operated on April 19, 1939, and was well two years later. Five others were operated on with good results. In 1941, Heinbecker and Barton⁸⁵ produced pericardial adhesions by insertion of an irritant into the pericardial cavity. In 1942, Thompson and Raisbeck¹⁸³ advocated talc instillation to produce pericardial adhesion. In 1943, Roberts and associates¹⁵⁹ performed experimental systemic artery coronary anastomosis, and in 1946, Vineberg¹⁹⁴ of Canada advocated implantation of internal mammary artery into the myocardium.

In 1956, Absolon and associates² advocated endarterectomy for coronary disease and did experimental work in anastomoses of the systemic and coronary vessels. In 1957, Bailey and associates¹⁵ reported 2 cases of successful endarterectomy of the coronary artery. In 1958, Vineberg¹⁹⁵ reported results of 1500 experiments in dogs using internal mammary implantation, and in 59 patients, 70 per cent of whom were able to work. Of the survivors, 78 per cent were able to work. In 1958, Longmire and co-workers¹²⁵ of Los Angeles reported 5 cases of coronary endarterectomy operated on since December, 1957. Later, they¹²⁶ reported 7 additional cases and 2 deaths. In 1962, Sones and Shirey¹⁷⁶ of Cleveland popularized coronary angiography. In 1965, Effler and associates⁵⁵ reported good results in 65 patients treated by internal mammary implantation into the myocardium after careful angiography.

Aneurysm of Thoracic Aorta

Moore¹³² of Great Britain, in 1864, threaded a fine wire into a thoracic aneurysm hoping it would clot and in 1879, Corradi^{42a} of Italy applied an electric current to the wire to favor thrombosis. In 1902, Tuffier¹⁹¹ of France ligated the neck of a saccular aneurysm on the ascending aorta and removed it, but the patient died on the thirteenth day. In 1910, Sauerbruch,¹⁶⁵ while operating on a patient with a supposed mediastinal tumor, opened a cardiac aneurysm. The cardiac musculature was sutured and the aneurysm excised. The patient was well four years later.

In 1944, while operating on a patient for what was thought to be a mediastinal tumor, I found a saccular aneurysm arising from the greater curvature of the arch of the aorta. When the lung, which was adherent to it, was freed, the aneurysm began to bleed. Because I feared it would blow out, I placed artery clamps across the base of the aneurysm and resected the aneurysm between the clamps. Interrupted mattress cotton sutures were inserted proximal to the clamp and tied. The patient made an uneventful recovery and is still living. This is apparently the first successful resection of a saccular aneurysm of the arch of the aorta.

In 1944, Alexander and Byron⁶ resected a saccular aneurysm of the arch of the aorta in which there was coarctation. The patient died one year later of cerebral hemorrhage. In 1948, Cooley and DeBakey^{41a} wrapped cellophane around the base of an aortic aneurysm; the patient died two

months later of hemorrhage. In 1953, the same authors^{41b} did the first successful resection and graft replacement of the thoracic aorta. In 1954, Shumacker⁷¹ and Hufnagel⁹⁶ independently used tubes to replace the aorta. In 1955, DeBakey and co-workers⁴⁸ reported the first successful repair of dissecting aneurysm of the aorta; 4 of their 6 patients recovered. In 1957, they⁵⁰ reported the first successful removal of the entire ascending aorta for a fusiform aneurysm, using cardiac bypass. In 1957, DeBakey and co-workers⁴⁹ reported results in 83 cases of thoracic aortic aneurysm. In 1957 Bailey and Gilman¹³ reported their experience with 9 patients with ventricular aneurysm, of whom 8 survived but with little improvement. In the same year, Cooley, DeBakey and Morris⁴² used extracorporeal circulation to excise an aneurysm.

Although the first operation performed was a thoracic one, thoracic surgery has actually developed within the past half century.

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Preoperative Evaluation and Management of Patients with Pulmonary Insufficiency

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The lung serves as a membrane for the exchange of gases between air and blood, and although we normally think of this as a relatively simple function, it is exceedingly complex, even in the normal person. The lung is unique in that it is the only vital organ in constant contact with air, and for this reason a potential hazard exists in any patient on whom an operation is to be performed.

In patients with chronic pulmonary disease and evidence of pulmonary insufficiency, a surgical procedure may be a serious threat to life. Special care is obviously necessary before, during, and after the operation. These patients may have limited pulmonary reserve, and further diminution may result in severe hypoxia, hypercapnia, and respiratory failure. The operation is an increased hazard because of the effects of pain and immobilization of the chest, use of anesthetic agents and narcotics, and inability of the patient to cough adequately and remove secretions.

PREOPERATIVE EVALUATION OF PATIENT

The incidence of postoperative collapse of pulmonary tissue is extremely high in patients with chronic pulmonary disease, and encroachment on the pulmonary function of a patient with limited pulmonary reserve will ultimately result in respiratory failure. Preoperative evaluation of a patient with chronic pulmonary disease is based upon his history and physical examination, and laboratory tests, including pulmonary function studies.

History and Physical Examination

The most important aspect of this part of evaluation of the patient is the suspicion that pulmonary insufficiency might exist. Such symptoms as

shortness of breath on exertion and cough are not always apparent, therefore the examiner must make a special effort to detect them from the history and physical examination. The character of the cough, its productivity or nonproductivity, the degree of dyspnea and whether it is associated with exhaustion, and even occurrence of thoracic pain as related to breathing or exertion are the most important clues to the possibility of underlying pulmonary insufficiency.

Laboratory Tests

Radiologic examination of the lung is of particular value in patients with diffuse bilateral disease, such as fibrosis and the granulomatoses. It is not as helpful in those with obstructive respiratory disease, unless both inspiratory and expiratory films are made to determine whether trapping of air is present. Pulmonary insufficiency is not demonstrable on roentgenography, and no abnormality may be detected in the roentgenogram of the chest of a patient with severely limited pulmonary reserve. Laboratory procedures other than the blood count offer little help¹ in patients with pulmonary insufficiency. The presence of polycythemia should be considered as being due to pulmonary disease until proved otherwise, since polycythemia is common in patients with hypoxia.

PULMONARY FUNCTION STUDIES. Simple tests of pulmonary function, investigating the mechanics of breathing and determination of the oxygen-carbon dioxide tension and pH in the arterial blood, should be performed on all patients suspected of having chronic pulmonary disease. Such tests provide information about the degree of insufficiency as well as a baseline on which to determine preoperative treatment, and the extent of the surgical procedure that the patient will tolerate. The postoperative morbidity and mortality rates can be considerably reduced if routine pulmonary function studies are performed on all patients with evidence of chronic pulmonary disease. These basic tests of pulmonary function do not require expensive, elaborate laboratory equipment. Some basic mechanics of breathing can be determined by simple spirometry.

PREOPERATIVE MANAGEMENT

Fishman¹ classified patients in whom pulmonary insufficiency might be suspected into three categories: (1) those with bilateral diffuse disease of the lungs, such as pulmonary fibrosis; (2) those with essentially normal lungs who have evidence of alveolar hypoventilation, and (3) those with obstructive pulmonary disease, which is the most common type.

Bilateral diffuse pulmonary disease can be detected on radiologic examination of the chest. These patients should have extensive pulmonary function studies before any surgical procedure is performed on them. It is often advisable before a contemplated major surgical procedure to attempt

to ascertain the correct diagnosis by lung biopsy. Rarely do these patients have difficulty once the cause of the disease is ascertained.

Alveolar hypoventilation in a patient with normal lungs can be recognized from a good history and physical examination and demonstration of increased carbon dioxide tension, decreased oxygen tension, and acid pH on pulmonary function tests. These patients should be treated intensively before operation and monitored closely during and after operation for evidence of profound rises in carbon dioxide or change in pH. Preoperative use of intermediate positive pressure breathing is of inestimable value in returning the carbon dioxide tension and pH to a normal level. Since the basic problem is one of increasing alveolar ventilation, the obvious answer to these patients' difficulties is to improve the mechanics of breathing and, therefore, alveolar ventilation. Congestive failure is a common complication of alveolar hypoventilation, and obviously should be treated with the usual method of salt restriction and digitalis and, if necessary, phlebotomy in polycythemic patients. These patients need to be artificially ventilated before any surgical procedure and, as stated before, watched very carefully throughout the operative and postoperative period.

The management of patients with *obstructive respiratory disease* involves the use of bronchodilators and expectorants, diaphragmatic breathing exercises, steroids, and preoperative intermediate positive pressure breathing. The use of bronchodilators, by aerosol or orally, is especially important. These patients have evidence of increase in respiratory resistance, which is partially reversible. Decrease in bronchomotor tone will not only improve respiration but also decrease the amount of secretions, as increased mucous secretion usually accompanies bronchomotor tone increase. Various theophylline and ephedrine compounds have proved effective in our patients. We use aerosol bronchodilators, in patients of various types, given to them on a regular basis four times a day with a hypertonic saline solution. In addition, an expectorant is given orally to liquefy secretions and decrease the effort of cough and, therefore, increase the probability of adequate bronchial toilet preoperatively.

In addition to use of bronchodilators and expectorants, the patient should quit smoking at least 72 hours, and preferably one week, before any surgical procedure. The irritant from smoke causes an increase in bronchorrhea and therefore makes induction of anesthesia, as well as the patient's postoperative convalescence, much more difficult.

The employment of diaphragmatic breathing has been of extreme value in preparing patients with obstructive respiratory disease, resulting in pulmonary insufficiency, for surgical procedures. Diaphragmatic or abdominal breathing increases tidal volume significantly, and in our experience it has been effective in relieving the sensation of dyspnea as well as increasing the productivity of the cough. This type of therapy is of little value unless the patient is instructed in method for at least a week before the operation.

Antibiotics have been used extensively in the preoperative treatment

of patients with pulmonary insufficiency. They are basic therapy in patients with infected bronchial secretions. We do sputum cultures on all patients with obstructive respiratory disease, or evidence of other pulmonary disease, and treat them preoperatively according to the sensitivities on the culture.

We reserve steroid therapy for patients with severe bronchospasm which cannot be relieved by the usual methods of treatment. Such patients usually have severe bronchial asthma. We do not prescribe steroid therapy for patients with obstructive pulmonary emphysema.

Intermittent positive pressure breathing preoperatively is not indicated in patients with obstructive respiratory disease. Only patients with alveolar hypoventilation are given this therapy. Tracheostomy is rarely necessary in the preoperative management of patients with obstructive respiratory disease and pulmonary insufficiency, although postoperatively it is important to maintain the patient's cough reflex adequately. We therefore use tracheostomy in patients during the immediate postoperative period only if they are unable to bring up the bronchial secretions. Adequate preoperative management of patients with pulmonary insufficiency should preclude use of tracheostomy in most patients.

CONCLUSION

Preoperative evaluation of patients with pulmonary insufficiency consists of a complete history and physical examination including roentgenography and pulmonary function studies. Most patients with pulmonary insufficiency have obstructive respiratory disease. In such patients the most important aspects of preoperative management are cessation of smoking and use of bronchodilators and expectorants.

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Evaluation and Preparation of Cardiac Patients for Thoracic Operations

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The extent of tests performed on patients with cardiac disease who are to undergo thoracic operations varies with the individual internist. At one extreme is the internist who believes that he must decide whether operation is actually indicated, as well as whether the patient's physical condition will tolerate the operation and the expected operative morbidity. At the other extreme is the internist who merely wants to determine whether the patient can survive the operation, and, if so, whether it will help or harm him. Lastly, the internist must decide when operation is definitely contraindicated. Preoperative evaluation of these patients is therefore a tremendous responsibility.

PREOPERATIVE EVALUATION

HISTORY. An adequate history must first be obtained. In addition, certain facts regarding the cardiovascular system must be ascertained. These include the possibility of generalized arteriosclerosis, exertional thoracic pain, previous myocardial infarction, or acute coronary insufficiency, as well as congestive heart failure, cardiac arrhythmias, transient cerebrovascular insufficiency, or "little strokes."

The patient should be questioned regarding previous drug therapy, particularly oral anticoagulant therapy, recent use of reserpine or its derivatives, or parenteral use of adrenocorticosteroids. He should be asked about previous blood transfusions or blood transfusion reactions, allergies, bleeding tendency, hypertension, and postural hypotension. Concurrent infection of the upper respiratory tract should be excluded, and the patient's smoking and coughing habits should be considered in relation to the anticipated anesthetic agent.

PHYSICAL EXAMINATION. In addition to performance of a general

physical examination the examiner should look for certain specific conditions:

1. *Evidence of left ventricular failure* may be obvious while talking with the patient. The physician should look for evidence of subclinical failure, since preoperative digitalization may benefit even the mildest form. Important physical signs include an apical diastolic gallop; pulsus arternans when the blood pressure is taken; tachycardia out of proportion to the patient's general physical condition; and, of course, the more overt signs of moist inspiratory rales at the pulmonary bases, hepatomegaly, and peripheral edema.

2. *Cerebrovascular Disease.* Careful attention should be paid to the quality of the pulsations in the carotid arteries bilaterally, and the presence or absence of bruits over the carotid arteries.

3. *Arrhythmia.* Although a history of transient arrhythmias might have been obtained, arrhythmia will not necessarily be detected on physical examination. Therefore, sufficient time should be devoted to listening to the patient's heart to be certain that he has no evidence of arrhythmia, particularly of ventricular irritability or physical signs suggestive of heart block.

4. *Blood pressure* should be recorded routinely, and the femoral and brachial pulses should be palpated simultaneously, to exclude the diagnosis of coarctation of the aorta. In addition, postural falls in blood pressure, if the blood pressure initially is modestly low, should be recorded to anticipate this difficulty.

5. *Examination of the lungs* will, in addition to giving a clue to the presence or absence of congestive heart failure, be of great help in detecting intrinsic underlying smoker's respiratory syndrome, emphysema, and other chronic pulmonary disease.

6. *Thyrotoxicosis.* Particular attention should be paid to the possible presence of signs suggestive of thyrotoxicosis. The patient should be observed for tremors of the hands, paralysis of convergence of the eyes, a lid lag, or evidence of excess sweating.

7. *Murmurs.* Obviously, the heart should be carefully auscultated for murmurs, since acquired valvular heart disease, as well as certain kinds of congenital heart disease, in themselves predispose patients to cardiac arrest or ventricular fibrillation. The undetected presence of mitral stenosis—a frequently undiagnosed condition because of the quiet nature of the murmur—will lead to complications if the patient receives large doses of atropine as preanesthetic medication. Likewise, severe aortic stenosis may lead to sudden cardiac arrest, which is refractory to standard treatment, if fall in peripheral vascular resistance and decrease in coronary perfusion occurs.

LABORATORY STUDIES. The minimal routine laboratory procedures in preoperative evaluation of these patients include complete blood count,

sedimentation rate, urinalysis, fasting blood sugar, blood urea nitrogen, serum sodium, potassium, uric acid and chloride determinations, carbon dioxide content and, in adults, electrocardiography and roentgenography of the chest. Routine determination of clotting mechanism is unnecessary in the absence of a suspicious history of bleeding or of recent anticoagulant therapy. Other laboratory tests are performed as indicated by the history and results of physical examination. Particular emphasis should be placed on the need for serum electrolyte determinations, since electrolytic abnormalities are frequently iatrogenically engendered by indiscriminate oral use of diuretic drugs. This laboratory information is particularly important, since altered electrolyte patterns may predispose to unexpected arrhythmias from otherwise routine drug therapy.

PREOPERATIVE PREPARATION

In preparing the cardiac patient for an anticipated thoracic operation, the physician must bear in mind many separate conditions:

1. Treatment of congestive heart failure, when present, is mandatory. This should include adequate bed rest, salt restriction, and administration of diuretics, and probably digitalis, to acquire and maintain a completely "dry weight" for the patient. Since depletion of serum electrolytes may occur as the result of too rigorous treatment of congestive heart failure, as well as some changes in the intravascular and extracellular blood volumes, sufficient time should be allowed after the dry weight has been achieved before operation is performed, which in my opinion should be at least 48 hours. In addition, in digitalized patients, efforts should be made to reduce the dosage of digitalis to a small maintenance dosage for at least 24 to 48 hours before operation, to lessen the possibility of ventricular irritability from excessive amounts of this drug. Lastly, the serum electrolyte level should be carefully checked before the day of operation, and hyponatremia or hypokalemia, if present, should be corrected before operation is performed.

2. In the patient with a history suggestive of arrhythmias—even simple, occasional, ventricular premature beats—treatment to correct this irregularity should be instituted. The electrocardiographic demonstration of multiple or multifocal ventricular premature beats is an ominous sign that requires vigorous treatment before operation. In both of these instances, quinidine or procainamide hydrochloride should be given in adequate dosage to suppress the irritable ventricular focus completely. The anesthesiologist should be informed that the patient had been receiving anti-arrhythmic agents, and procainamide should be immediately available for intravenous administration in adequate dosage to suppress ventricular irritability if it should occur during the operation. Monitoring the electrocardiogram during

operation, if possible, is prudent to anticipate impending ventricular tachycardia or fibrillation and to institute intravenous infusion of procainamide at the proper time.

Parenteral administration of quinidine generally is extremely hazardous. Most cardiac patients with a recent history of ventricular irritability can be safely operated on if they receive procainamide intravenously in the event that further arrhythmias occur during the operation. In an occasional patient, adequate doses of procainamide will cause severe hypotension so that it becomes mandatory to administer quinidine parenterally instead. Adequate electrocardiographic monitoring then becomes mandatory. If intravenous administration of procainamide becomes necessary during operation, it should be continued immediately after operation until the patient is able to start taking quinidine orally.

3. If the patient had received adrenal corticosteroids recently, particularly in large doses parenterally, it is advisable to give him 300 mg. of cortisone the day before operation and the day of operation, and then to taper the dosage gradually during the next ten days. If, on the other hand, the patient had taken smaller doses of adrenal corticosteroids some time before, the anesthesiologist should be warned that the stress of the operation might cause the blood pressure to fall as a result of adrenal insufficiency, and hydrocortisone should be immediately available for intravenous administration if hypotension develops.

4. Some cardiologists advise that patients discontinue taking drugs containing *Rauwolfia* or one of its derivatives at least 10 to 14 days before operation, but we have experienced little difficulty with cardiac patients operated on after having taken these drugs and therefore do not consider their recent use a contraindication to operation.

5. Patients receiving long-term oral anticoagulant therapy or long-term intramuscular heparin injections require special preoperative attention. Although some operations can be performed on patients who are taking anticoagulants, this is not true of thoracic operations. Therefore, anticoagulant therapy should be discontinued before a thoracic operation is performed. In the case of heparin, this generally presents no problem. Since protamine is a specific antidote for heparin on a milligram-to-milligram basis, anticoagulant therapy may be continued until the patient is to be brought to the operating room, when a dose of protamine equal to his last dose of heparin may be administered.

Vitamin K₁ oxide, given intravenously, is a specific antidote for oral anticoagulants, but this drug entails a slightly greater risk since untoward reaction may occasionally occur with too rapid administration of the drug and since induction of hypercoagulability is a possibility. Therefore, it should be used only when an emergency surgical procedure must be performed. In all other instances, the dosage of anticoagulant should be tapered off during a period of ten days before operation, and careful atten-

tion should be paid both to the prothrombin time and, when available, the thrombotest, to determine whether all factors (II, VII, IX, and X), which are depressed by oral anticoagulant drugs, have returned to nearly normal levels. Often, when the prothrombin time is relied on alone, it may appear normal, and yet bleeding may be serious, because of failure of factor IX (not reflected in prothrombin time determinations) to have also reached a normal level.

The problem of hypercoagulability of the blood after discontinuance of oral anticoagulant therapy has never been settled, although statistical studies have shown an increased incidence of thrombotic episodes with abrupt cessation of oral anticoagulant therapy. This is another reason for gradual reduction in dosage of anticoagulant therapy during a period of ten to fourteen days, if possible, with the hope of preventing this increase of thrombotic tendency.

Lastly, serious consideration must be given to the initial reason for oral anticoagulant therapy; the potential danger engendered by cessation of therapy in some patients with severe coronary insufficiency, or progressively severe angina, might make cessation of therapy more hazardous than foregoing the suggested thoracic procedure. Therefore, the advantage of the operation must be weighed carefully against the potential risk of cessation of the therapy.

6. The patient should not smoke for at least several days before operation to prevent accumulation of secretions in the lungs. Patients with bronchospastic disease should be treated with bronchodilators and inhalants preoperatively to improve their ventilatory capacity.

7. Anemia, when present, should be corrected to a reasonable level, although transfusions for patients whose hemoglobin is above 12 grams are not indicated. Generally, there is never indication for one blood transfusion. Blood volume determinations may be of some help, particularly in patients who have been treated for congestive heart failure, and the exact status of the plasma volume is unknown. These determinations have the added advantage of serving as a baseline for comparison with postoperative blood volume determinations, since replacement of blood is still far from an accurate science.

8. Evaluation of the electrocardiogram in relation to treatment of the patient preoperatively is difficult and treacherous. Evidence of ventricular irritability obviously must be corrected, but except for this, little emphasis need be placed on the electrocardiographic tracing in the absence of overt evidence of myocardial ischemia, recent myocardial infarction, or drug intoxication, since it may be normal in the patient with severe coronary disease or abnormal in the patient without coronary disease. The preoperative tracing may be of help primarily as a basis for comparison, should postoperative complications indicating change in cardiovascular status develop.

DISCUSSION

Since coronary artery disease is the greatest threat to life in the adult older than 40 years of age in whom a major thoracic procedure is contemplated, this condition must always be considered. Reported mortality and morbidity rates in patients with coronary artery disease undergoing surgical procedures vary. Arkins and associates¹ reported that the mortality rate for routine surgical procedures in patients with coronary artery disease was twice that of other patients. Moreover, it was 40 per cent in patients who had had myocardial infarctions less than three months before operation as contrasted with 22.3 per cent in cardiac patients who had not had recent myocardial infarctions. Lastly, they stated that postoperative myocardial infarction carried a mortality rate of 69 per cent. Therefore, it is important to know if a patient has coronary disease and if he has had a recent myocardial infarction. Also, angina, particularly if it is increasing in frequency or severity, greatly increases the surgical risk. These statistics are the latest available on a large series of patients with heart disease undergoing surgical procedures. There is no doubt that the operative mortality rate is increased in cardiac patients but it is my conviction that the mortality rate in such patients at our institution is not as high as these figures, because patients have been properly selected and given adequate preoperative treatment.

In view of these statistics, however, the physician undertaking preoperative evaluation of patients must exclude asymptomatic coronary disease, which may be present despite extensive normal roentgenographic, electrocardiographic, and hematologic observations. Again, the history is probably the most important single feature in determining the possibility of coronary disease. At this time, the final resort would appear to be selective cine-angiocardiology of the coronary arteries, which, although safe, is so time-consuming, technically difficult, and expensive that it would be impractical as a routine procedure for patients undergoing elective thoracic operations.

Hypertension in itself is not a contraindication to elective thoracic operations. In hypertensive patients the diagnosis of pheochromocytoma, of course, must be excluded before any surgical procedure is performed, since these patients may react poorly to anesthetic agents.

In the treatment of patients with varying degrees of atrioventricular block, great care should be exercised to prevent Adams-Stokes attack. To this end, if the patient is known to have had Adams-Stokes attacks, or to have varying degrees of atrioventricular block, it seems advisable either to implant a transvenous pacemaker catheter through the right jugular vein into the right ventricular apical area with a pacemaker available for attachment or at least to have adequate facilities available for immediate institution of external cardiac pacing. Of the two, use of the transvenous cardiac pacemaker seems more desirable, and, if an elective prolonged thoracic operation is contemplated in patients with known atrioventricular block,

it is recommended that a venous pacemaker catheter be routinely placed into the right ventricle before induction of anesthesia. This is particularly important, because most instances of cardiac arrest occur during induction of anesthesia.

Finally, every effort must be made to minimize the patient's apprehension about the operation, since coronary disease is particularly aggravated by anxiety. To this end it seems prudent to give the patient moderate to heavy doses of sedatives while he is still in his room, and to avoid prolonged waiting before operation is performed. Also, if possible the physician with the best rapport with the patient should be with him at least until the moment of anesthetic induction.

SUMMARY

Coronary artery disease is the greatest hazard to patients undergoing elective thoracic operations, and careful study should be undertaken to determine its presence, since coronary disease may be asymptomatic. Coronary disease at least doubles the operative mortality rate. A recent attack of acute myocardial infarction doubles this mortality rate, and post-operative myocardial infarction proves fatal in about 70 per cent of patients. No elective thoracic operation should be performed within three months after an attack of myocardial infarction.

Congestive heart failure must be controlled, and at least two days should elapse after diuretic therapy or excessive digitalization before operation is performed. Electrolyte balance must be achieved before operation. Blood volume determinations may be extremely important, particularly in patients undergoing treatment for congestive heart failure. Cessation of anticoagulant therapy with a proper program is necessary to prevent complications.

Attention must be paid to recent corticosteroid therapy, to prevent the possibility of adrenal shock. Anemia should be corrected. Attention should be paid to the respiratory tract to prevent excessive bronchial secretions.

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Perfusion Lung Scanning in Evaluation of Patients with Bronchogenic Carcinoma

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Use of scintillation scanning of the lungs after an intravenous injection of radioiodinated macroaggregated albumin ($^{131}\text{IMAA}$) to demonstrate regional blood flow within the lung has been well documented.^{2, 5, 6-9} This technique has proved to be a safe, sensitive method for demonstrating abnormal blood flow through the pulmonary artery in a wide variety of diseases. Most reported experience with this technique has been to demonstrate abnormalities produced by pulmonary embolism, pneumonia, and chronic pulmonary disease. We² previously reported the value of lung scanning in the evaluation of patients with bronchogenic carcinoma. Additional experience has substantiated this observation.

METHOD

The day before administration of the macroaggregated albumin, 1.5 cc. of Lugol's solution is given in three doses to block the thyroid gland. This step decreases the amount of ^{131}I reaching the thyroid gland as the iodine is broken free from the macroaggregated albumin during its metabolism in the body. Just before scanning, 200 $\mu\text{c.}$ of the $^{131}\text{IMAA}$ is injected intravenously with the patient recumbent. Scanning of the lungs is started immediately as the 100 micron particles of the $^{131}\text{IMAA}$ lodge in the pulmonary capillaries upon initial passage through the lungs. Lung scans are obtained with a commercially available 3-inch scintillation scanner which records the scan data on the film through a photorecording mechanism.

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Routinely, anteroposterior and postero-anterior projections are obtained. Under certain circumstances, a lateral scan may be of value.

PERSONAL EXPERIENCE

In our first 50 patients, the lung scan demonstrated abnormal blood flow in the pulmonary arteries of all but 2 patients with proved bronchogenic carcinoma. The following cases demonstrate the advantages and limitations of perfusion lung scanning.

CASE I. A 70-year-old white man came to the Clinic complaining of pain in the right arm and shoulder for the preceding three months. A mass at the apex of the right lung with destruction of the posterior portion of the right second rib was visualized in the roentgenogram of the chest (Fig. 1, *A*). On cytologic examination of the sputum, malignant cells were found. The lung scan on the anteroposterior projection showed a normal pattern for both sides of the lung. The cardiac silhouette in the inferior medial aspect of the left side is well shown in this view (Fig. 1, *B*).

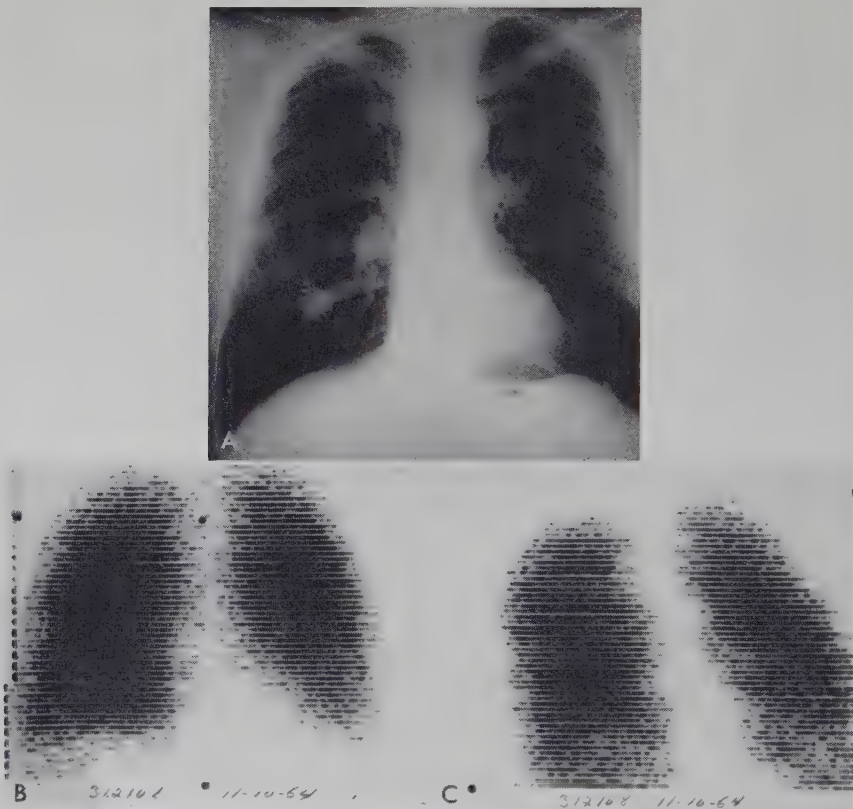


Figure 1. *A*, Pancoast tumor of the right apex with invasion of the posterior portion of the right second rib. *B*, Anteroposterior lung scan appears normal. *C*, Postero-anterior lung scan again shows no abnormality.

The postero-anterior projection (Fig. 1, *C*) also failed to demonstrate any abnormality in the apex of the right side of the lung other than that attributable to minimal old scarring. On the posterior projection, the cardiac outline was not well shown in the inferior position of the left pulmonary field.

CASE II.* A 52-year-old man consulted us because of persistent nonpleuritic soreness in the left hemithorax laterally and anteriorly, apparently aggravated by change in position. The patient had lost 10 pounds in weight during the previous month and had had progressive increase in cough for the preceding three years. The sputum contained malignant cells on three examinations. A nodular mass was noted inferior to the left hilum on roentgenography of the chest (Fig. 2, *A*). The antero-posterior lung scan appeared normal (Fig. 2, *B*), but the lateral film of the chest demonstrated that inability of the lung scan to show the lesion was due to its location in the apical portion of the left lower lobe (Fig. 2, *C*). The posterior location of the lesion was out of range of focus of the scanner's collimeter, which is about 3 inches. Had a postero-anterior projection been obtained, the lesion probably would have been visualized.

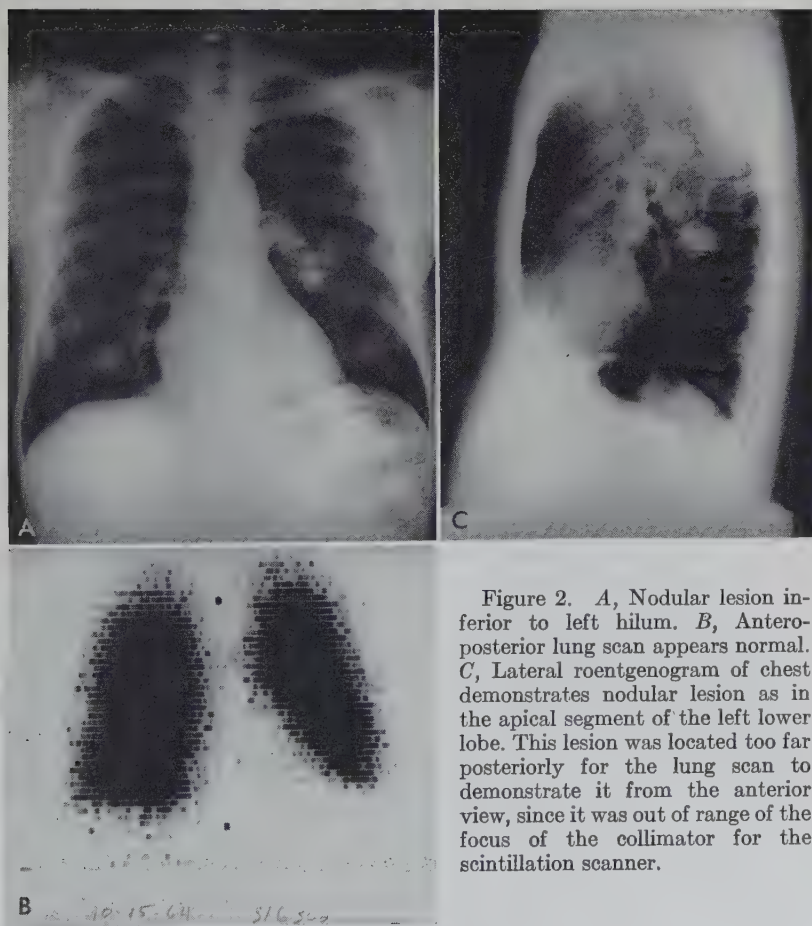


Figure 2. *A*, Nodular lesion inferior to left hilum. *B*, Antero-posterior lung scan appears normal. *C*, Lateral roentgenogram of chest demonstrates nodular lesion as in the apical segment of the left lower lobe. This lesion was located too far posteriorly for the lung scan to demonstrate it from the anterior view, since it was out of range of the focus of the collimator for the scintillation scanner.

* Previously reported by Hatch and associates.²

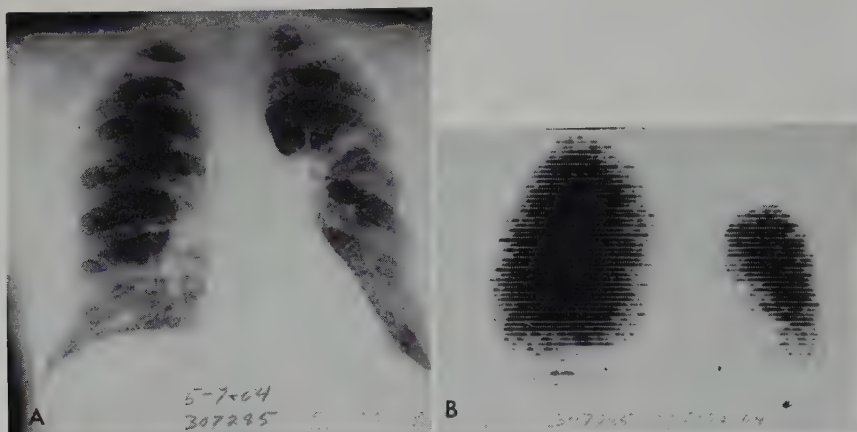


Figure 3. A, Mass in left hilum; left pulmonary field otherwise appears normal. B, Lung scan shows no pulmonary artery flow to the left upper lobe.

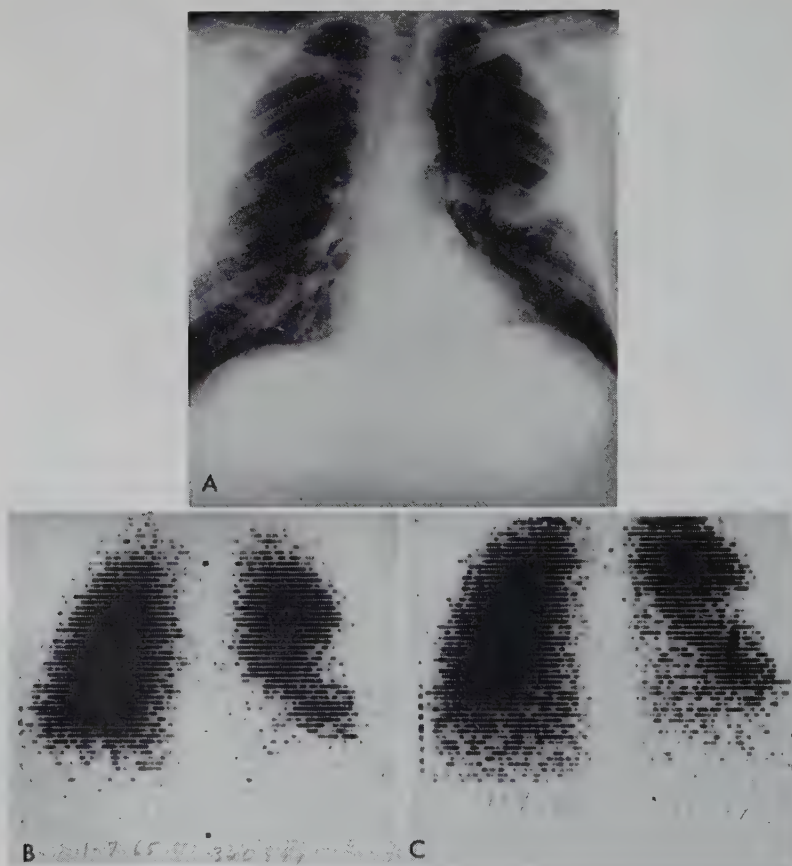


Figure 4. A, Nodular lesion in left midpulmonary field with extension to the pleural surface. B, Anteroposterior lung scan shows defect in left lung that corresponds to the size of the nodular lesion. C, Postero-anterior lung scan again demonstrates lesion in left pulmonary field with no other abnormality.

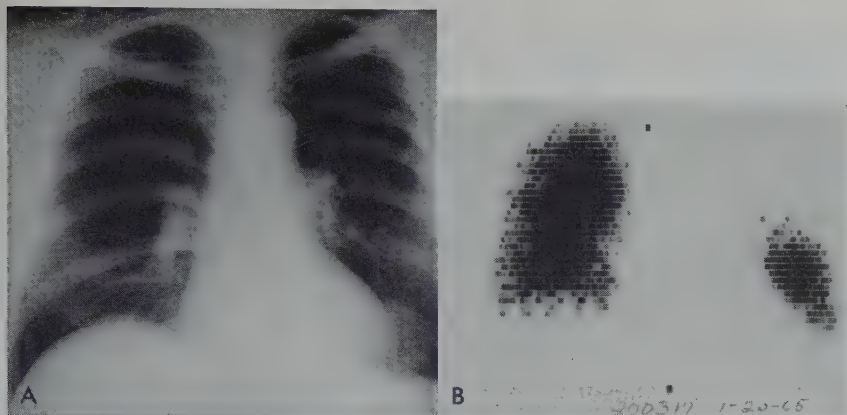


Figure 5. A, Roentgenogram interpreted as showing no abnormality in patient with positive result of cytology and hemoptysis. B, Anteroposterior lung scan demonstrates lack of pulmonary artery blood flow to left upper lobe.

CASE III. A 52-year-old white man came to the Clinic because of thoracic pain and loss of weight for several weeks. The sputum contained no malignant cells on three separate examinations. In the roentgenogram of the chest, a mass was visualized in the left hilum with extension into the left pulmonary field (Fig. 3, A). The diagnosis of metastatic bronchogenic carcinoma was made by biopsy of the right third rib. The lung scan demonstrated obstruction of blood flow to the upper half of the left pulmonary field (Fig. 3, B). The pronounced interference with blood flow to the left lung was not appreciated on routine roentgenography of the chest.

CASE IV.* A 58-year-old white man was referred to us for evaluation of a mass in the left lung detected on routine roentgenography performed because of high fever that developed after appearance of a furuncle on the hand. Five days after development of the furuncle, pleuritic pain was experienced on the left side of the chest. On roentgenography of the chest a mass was visualized in the mid-left pulmonary field with extension to the pleural surface (Fig. 4, A). A defect the size of the mass was demonstrated on both the anteroposterior and postero-anterior lung scans (Fig. 4, B, 4, C). No other abnormality on the lung scan was identified. The minimal decrease in localization in the inferior medial aspect of the left lung on the postero-anterior projection can be produced by slight cardiomegaly.

CASE V.* A 72-year-old man came to the Clinic because of blood-streaked sputum noted several weeks before admission. At that time, he was admitted to the local hospital for evaluation. No abnormalities could be detected on roentgenography of the chest or bronchoscopy. The patient stopped smoking, and for two weeks he had no cough or bleeding. When the hemoptysis recurred, he consulted us. The routine roentgenogram of the chest showed no abnormalities (Fig. 5, A). On physical examination no abnormality could be detected. The lung scan demonstrated absence of blood flow to the left upper lobe of the lung (Fig. 5, B). At pneumonectomy, nodes in the left hilum were found to be compressing a pulmonary artery. The pulmonary arteries had not been invaded.

CASE VI. A 48-year-old man consulted us because of loss of weight, malaise, and cough of several months' duration. On roentgenography of the chest a large mass was demonstrated in the left hilum with pleuritic masses in both lateral pulmonary fields and metastasis to the anterior portion of the right second rib (Fig.

* Previously reported by Hatch and associates.²

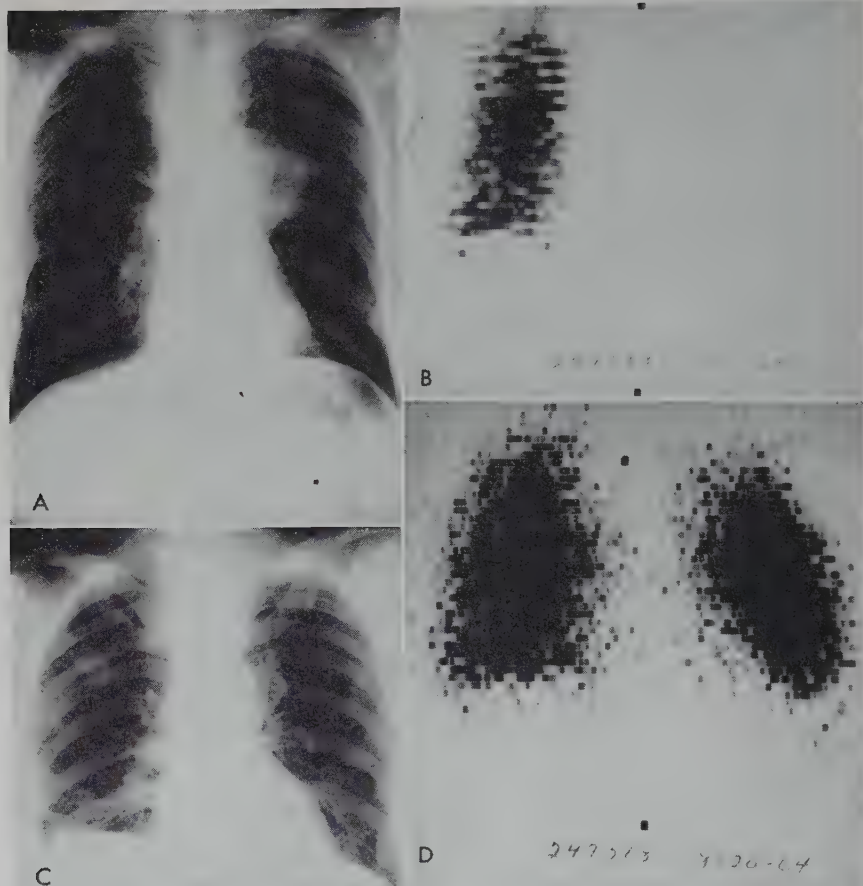


Figure 6. *A*, Mass in the left hilum with pleural metastasis bilaterally and involvement of the anterior end of the right second rib. *B*, Lung scan, though technically poor, demonstrates no pulmonary artery blood flow to the left lung. *C*, Roentgenogram six weeks after completion of radiation therapy to the mediastinum and left hilum demonstrating regression of the left hilar lesion but progression of other metastatic lesions. *D*, Lung scan shows return of pulmonary artery perfusion to the left lung six weeks after radiation therapy.

6, *A*). The roentgenogram, however, did not indicate absence of pulmonary artery perfusion to the left lung, which was clearly demonstrated by the lung scan (Fig. 6, *B*). Although metastasis was present, radiation therapy to the mediastinum and left hilum was employed because of beginning dysphasia and the possibility of infection secondary to almost complete obstruction of the left mainstem bronchus. Irradiation resulted in considerable shrinkage of these areas with subjective improvement though the metastatic lesions progressed (Fig. 6, *C*). Lung scan six weeks after completion of radiation therapy showed return of normal pulmonary artery blood flow to the left lung (Fig. 6, *D*).

CASE VII. A 35-year-old white man consulted us because of cough and anterior thoracic pain for three weeks. The routine roentgenogram (Fig. 7, *A*)

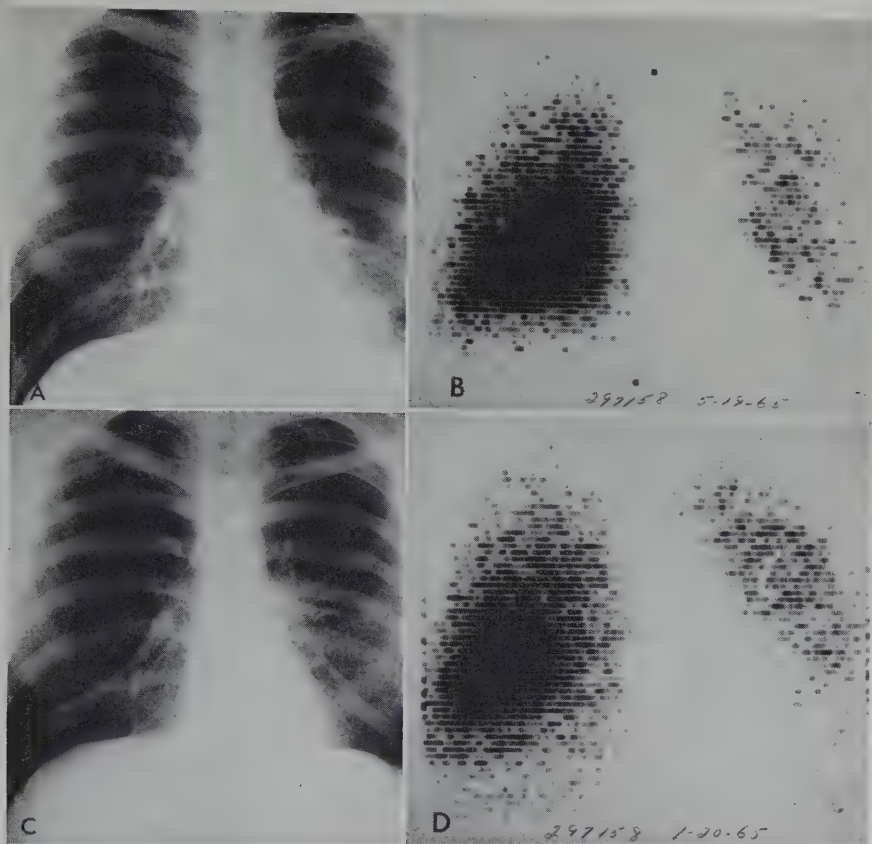


Figure 7. *A*, Infiltrate in pericardial area of left pulmonary field in patient with positive result of cytology and thoracic pain. Left pulmonary field otherwise appears normal. *B*, Anteroposterior lung scan shows considerable interference of pulmonary artery perfusion to the entire left lung. *C*, Apparent improvement one month after radiation therapy to the mediastinum and left hilar area. *D*, Lung scan shows no improvement in pulmonary artery blood flow to the left lung after radiation therapy.

showed increased prominence of the inferior portion of the left hilum. The sputum contained malignant cells. At exploratory thoracotomy invasion of the pericardium and mediastinum was extensive enough to make resection inadvisable. The biopsy diagnosis was metastatic undifferentiated carcinoma. The lung scan demonstrated great decrease in flow to the entire left lung (Fig. 7, *B*). The slight decrease in flow to the superior portion of the right lung was considered to be due to fibrotic scarring. Radiation therapy to the mediastinum and left hilar area resulted in apparent improvement (Fig. 7, *C*). The patient noted considerable decrease in pain and improvement in breathing. The lung scan obtained at the same time (Fig. 7, *D*), however, showed no improvement in pulmonary artery blood flow to the left lung. Recurrence of the tumor in the left hilar area substantiated the incomplete response to irradiation shown by the lung scan. The patient eventually died from hepatic metastasis. At necropsy, the primary tumor was found to be carcinoma of the tail of the pancreas.

CASE VIII. A 59-year-old white man was referred to us for evaluation of a mass in the inferior portion of the right hilum detected on routine roentgenography

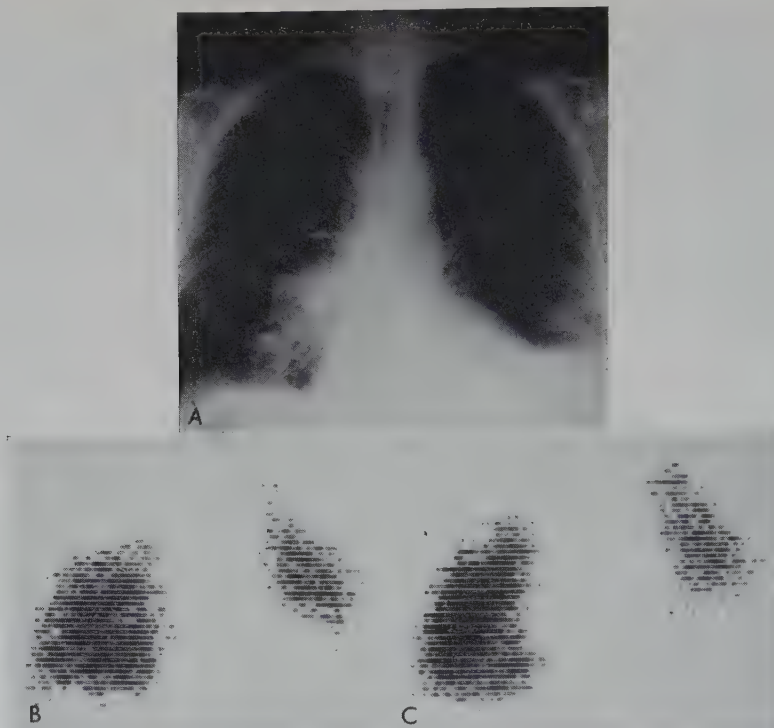


Figure 8. A, Mass in the right lower pulmonary field in a patient with positive sputum cytology. Pulmonary fields otherwise appear normal. B, C, Considerable decrease in blood flow to the superior portion of the right pulmonary field and decreased flow to the left pulmonary field. Pulmonary function studies confirmed abnormal perfusion as demonstrated on the lung scan.

(Fig. 8, A). Pulmonary function studies showed mild hypoxia, with mild, uncompensated respiratory alkalosis though ventilation was normal. The sputum contained malignant cells. The lung scan demonstrated that though the lesion was located in the right lower lobe, perfusion of the right lung was predominantly in the lower lobe with no flow to the upper lobe, and that flow to the entire left lung was greatly decreased (Fig. 8, B, C). This pattern of perfusion of the pulmonary fields shown by the lung scan, together with the abnormal pulmonary function, contraindicated removal of the lesion.

DISCUSSION

Perfusion lung scanning is a safe method of providing useful information in addition to that obtained from routine roentgenography in evaluation of the patient with known or suspected bronchogenic carcinoma. The information obtained from the perfusion lung scan is the same as that obtained from angiography of the pulmonary arteries but the method is safer and less traumatic.^{8, 9} The pattern of abnormal blood flow demonstrated by

the lung scan is not specific for bronchogenic carcinoma. The lung scan, therefore, must be interpreted in light of the symptoms, result of cytologic examination of the sputum, and roentgenographic observations.

Cases I and II demonstrate that small peripheral lesions or failure to obtain the correct view of the lung scan may yield a normal scanning pattern even though abnormality within the pulmonary field exists. Such an occurrence is apparently rare, since in all but 2 of our 50 patients with bronchogenic carcinoma, some abnormality of regional blood flow was demonstrated. The two most frequently observed patterns in bronchogenic carcinoma are those demonstrated in Case III with a mass in the hilar area obstructing circulation to a segment or lobe of the lung and in Case IV with a peripheral lesion which shows only a defect on the lung scan that corresponds to the size of the lesion. In disagreement with the opinion of Dotter,¹ the pattern of abnormal pulmonary artery blood flow demonstrated by Case III is not an indication of a nonresectable tumor. In most of our patients the abnormal circulation was produced by nodes pressing on the pulmonary artery rather than invading it.

In several patients with malignant cells in the sputum and normal roentgenograms of the chest, the lesion has been located by lung scanning. Case V is an example. Had the bronchoscopist not known of the abnormality in the left upper pulmonary field, the lesion in the upper lobe bronchus might have been missed, since it was visualized only through the right angle bronchoscope and a determined search for the cause of the abnormality noted on the lung scan.

Cases VI and VII are examples of use of the lung scan to demonstrate the result of radiation therapy. A lung scan may be of greater help in evaluating the effect of the course of radiation therapy than is in the routine roentgenogram.

Perhaps one of the greatest values of the lung scan is to visualize the areas of abnormal pulmonary artery perfusion in patients with abnormal pulmonary function. We have noted excellent correlation between an abnormal pattern in the lung scan and abnormal pulmonary function. Case VIII is an example of such correlation.

SUMMARY

The perfusion lung scan with radioiodinated macroaggregated albumin (¹³¹IMAA) is a safe, sensitive procedure that has been an aid in evaluation of patients with known or suspected bronchogenic carcinoma. It may help in the initial diagnosis or may show that the disease is more extensive than indicated by routine roentgenograms. It may also confirm the fact that other pulmonary disease would make removal of the lesion inadvisable. The lung scan can also be used to follow the course of the disease after therapy.

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Surgical Biopsy of the Lung

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Since the original description of diagnostic use of surgical biopsy of pulmonary tissue,* numerous reports have appeared concerning its value. During the past ten years we have used this technique on 150 patients with bilateral diffuse pulmonary disease in whom the diagnosis could not be established by the less formidable procedures of cytologic examination of the sputum, bronchoscopy, and scalene node biopsy. Lung biopsy is not advocated in patients with pulmonary lesions which might be amenable to pulmonary resection.

TECHNIQUE

In most patients the procedure can be performed through a limited anterior or anterolateral thoracotomy incision with use of a local anesthetic. As the pleural defect is usually less than 2 cm. in diameter, only the pulmonary tissue in the immediate vicinity of the lung is safely accessible. More than 90 per cent of our patients tolerated the procedure extremely well with only local anesthesia. Administration of oxygen by simple face mask seems to be better tolerated than the use of an anesthetic requiring an intratracheal tube.

When the patient arrives in the operating room, the anesthesiologist gives him a "test run" of positive pressure oxygen breathing by face mask to familiarize him with the sensation he will experience. Field block anesthesia in the area of the proposed incision is obtained with one of the conventional local anesthetics, our preference being a 1 per cent solution of procaine. A 3- to 4-inch horizontal incision is made in the skin just below the areola in male patients and in the inframammary crease in female patients.

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* Klassin, K. P., and Curtis, G. M.: Biopsy of diffuse pulmonary disease. *Arch. Surg.* 59: 694, 1949.

The fibers of the pectoral muscle are separated by blunt dissection, and the intercostal muscles are exposed. The anesthesiologist then applies the face mask and administers oxygen under gentle pressure. The interspace and underlying pleura are opened by blunt dissection, and the lung is exposed. The underlying lung is examined by inspection and palpation with the fingertip. By gentle traction with Allis forceps a sizable piece of pulmonary tissue can be brought through the small opening in the chest, if the anesthesiologist keeps the lung in a state of partial inflation. In this manner any tissue that seems more likely to provide diagnostic data than another can be isolated. Overlapping sutures of cotton are placed in such a way as to outline a V-shaped segment about 1.5 cm. in diameter in the edge of the lobe. Ligation of these sutures satisfactorily controls leakage of blood and air, and trauma to the specimen is minimal. The specimen is placed in a Petri dish and submitted to the pathologist for bacteriologic and histologic study.

A small thoracotomy tube is brought out of the wound, and -10 cm. of water negative pressure suction is applied. Usually a No. 20 or 22 French catheter is sufficiently large for re-expansion of the lung. The pleura and intercostal muscles are reapproximated with interrupted sutures about the catheter and the muscle and fascia of the thoracic wall and subcutaneous tissue of the skin are closed. The catheter is attached to underwater seal, and the anesthesiologist continues to administer oxygen under pressure until all the trapped air in the pleural space has been evacuated.

Pain in the wound and intrapleural cavity is controlled with small doses of analgesics, and the patient can sit up at the bedside within a few hours. The thoracotomy tube is removed upon cessation of leakage of air and fluid, generally within 12 to 24 hours. The patient is usually able to leave the hospital by the third or fourth postoperative day.

In Table 1 is shown the distribution of cases according to microscopic

Table 1. *Distribution of 150 Cases of Lung Biopsy According to Microscopic Diagnosis*

DIAGNOSIS		CASES
Fibrosis		78
Granulomas		33
Nonspecific	11	
Sarcoid	10	
Silicosis	8	
Eosinophilic	2	
Tuberculosis	2	
Neoplasms		28
Pneumonitis		11
Nonspecific	10	
Lipoid	1	
TOTAL		150

diagnosis in the 150 cases of lung biopsy. There were no serious complications in this series. Ten per cent of our patients had minimal residual pneumothorax, which required no treatment. No cases of subcutaneous emphysema or infection and no deaths were attributable to the procedure.

DISCUSSION

The increasing incidence of bilateral diffuse pulmonary disease is directly related to the increase in use of roentgenography, and also, to a certain extent, to the increased recognition of the importance of industrial medicine, particularly as it concerns the prevention of pneumoconioses. Before the availability of lung biopsy, direct examination of pulmonary tissue could be accomplished in one of two ways. One was exploratory thoracotomy, which is a formidable procedure, requiring an appreciable period of hospitalization and entailing significant morbidity. Moreover, pulmonary insufficiency often contraindicates its use. The other method of direct examination of pulmonary tissue is needle biopsy of the lung, which is a rather haphazard method of obtaining pulmonary tissue, particularly in patients with bilateral diffuse disease. The chances of obtaining an adequate specimen in our experience have been small.

There are, therefore, definite indications for lung biopsy. Probably the most important is to establish a definitive diagnosis. All our patients had complete evaluation of pulmonary function before biopsy. In all patients, other diagnostic procedures failed to be conclusive. The procedure is also valuable in patients with ventilatory diseases or the occupational pneumoconioses. With a specific diagnosis the physician can plan more appropriate treatment in such cases.

Lung biopsy is of value obviously to initiate proper therapy. This pertains specifically to steroid therapy in patients with diffuse bilateral disease. In our experience this use has been of most value in the granulomatous diseases.

Lung biopsy has also proved of value in patients with unilateral disease in whom pulmonary insufficiency was severe enough to negate thoracotomy. This is an unusual use of lung biopsy but a practical one.

The following cases illustrate the value of lung biopsy.

CASE I. A 63-year-old man was admitted to Ochsner Foundation Hospital with progressive shortness of breath during the preceding three or four months, cough productive of voluminous amounts of clear mucoid sputum, and loss of approximately 16 pounds in weight.

The sedimentation rate was elevated. On roentgenography of the chest bilateral pulmonary disease with a reticular pattern involving predominantly the lower lobes and midzonal areas was demonstrated (Fig. 1, *A*). Lung biopsy revealed lymphangitic carcinoma (Fig. 1, *B*), which was believed to be due to carcinoma of the pancreas. Postmortem examination confirmed this impression.

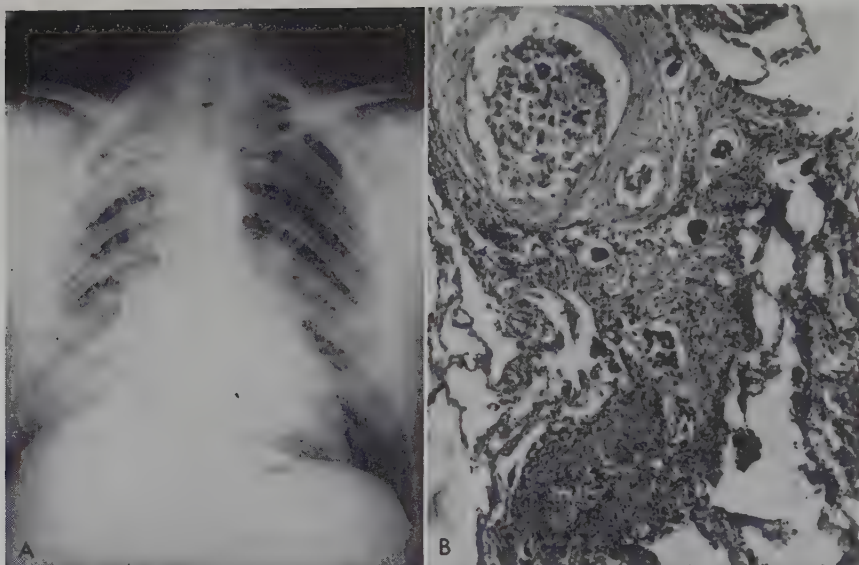


Figure 1 (Case I). *A*, Roentgenogram of chest showing diffuse bilateral pulmonary disease. *B*, Photomicrograph of lung biopsy specimen showing carcinoma within the lymphatics of the lung with minimal thickening of the alveolar septa. ($\times 100$).

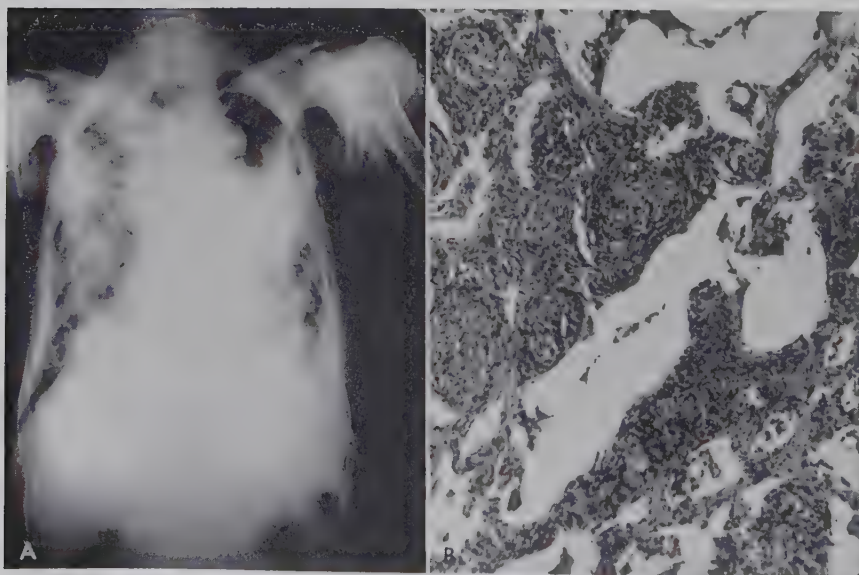


Figure 2 (Case II). *A*, Roentgenogram of the chest showing bilateral coalescent nodular disease. *B*, Photomicrograph of lung biopsy specimen showing severe fibrotic changes involving the pulmonary parenchyma associated with some nodularity. ($\times 100$).

CASE II. A 59-year-old man was admitted to Ochsner Foundation Hospital with the complaint of progressive shortness of breath, during a period of ten years. The patient had worked in sandblasting for years. Bilateral coalescent nodular disease was demonstrated on roentgenography of the chest (Fig. 2, A). Lung biopsy revealed silicosis with severe interstitial nodular fibrosis (Fig. 2, B).

CONCLUSION

Surgical biopsy of the lung has been a valuable adjunct in the diagnosis and treatment, and sometimes prognosis, of patients with diffuse, bilateral pulmonary disease. It is of extreme value in understanding better the basic pathologic physiology of disease.

Diagnostic Thoracoscopy

HURST B. HATCH, JR., M.D.

PAUL T. DECAMP, M.D.

Pathologic and bacteriologic examinations of visually selected portions of the pleura provide useful information in the diagnosis of pleural disease. Specimens may be obtained by surgical exploration, but to be done properly, general anesthesia and formal thoracotomy are required. In the presence of a free pleural space, as evidenced by pleural effusion or pneumothorax, the diagnosis may be achieved as accurately, and much more simply, by inspection and thoracoscopic biopsy of the pleura with use of a local anesthetic.

The thoracoscope is a thoracic endoscope introduced by Jacobaeus^{1, 2} in 1910 as a *diagnostic* tool. At the height of popularity of induced pneumothorax collapse therapy for pulmonary tuberculosis, the instrument was used almost exclusively to lyse adhesions which were preventing adequate collapse of the lung by the pneumothorax. Its diagnostic potential was forgotten, and with the passing of pneumothorax therapy, thoracic physicians and surgeons, particularly in the United States, discarded this valuable instrument.

In Europe the thoracoscope is still widely used as a diagnostic tool. Sattler³ of Vienna used it in hundreds of patients and published numerous reports of his experience.

EXPERIENCE OF THE OCHSNER CLINIC

Our experience with diagnostic thoracoscopy, though much more limited, has been so gratifying that we urge its widespread use. This paper presents our experience with this technique in 50 consecutive patients with pleural effusion. All patients were admitted to the Ochsner Clinic with a diagnosis of pleural effusion of unknown origin. Routine diagnostic studies were accomplished, usually including skin tests and sputum studies for acid-

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fast bacilli, fungi, and malignant cells. In 40 per cent, bronchoscopy with or without scalene node biopsy was performed. Thoracentesis, often repeated, with cytologic and bacteriologic studies, was performed. In this series the diagnosis remained uncertain after clinical evaluation and performance of the foregoing studies.

Symptoms

The symptoms were those that would normally be expected in patients with pleural irritation. Twenty-two had dyspnea, 21 thoracic pain, 11 cough, 4 fever, and one abdominal pain. Four patients were asymptomatic, pleural effusion having been discovered incidentally by physical or roentgenologic examination.

Technique

The diagnostic thoracoscope (Fig. 1) consists of a biopsy forceps (A), two pencil-sized trocars (B, C), two diamond pointed obturators (B, D), an endoscope (E) which may be inserted through the trocar, and a long needle with which local anesthesia of the pleura may be effected. It is important *not* to completely aspirate pleural fluid or air before thoracoscopy, as this greatly complicates finding a free pleural space into which to insert the thoracoscope. After needle aspiration confirms the presence of a free pleural space at a particular location, a stab wound of the skin is made, and a trocar is inserted between the ribs by means of a diamond-pointed obtura-

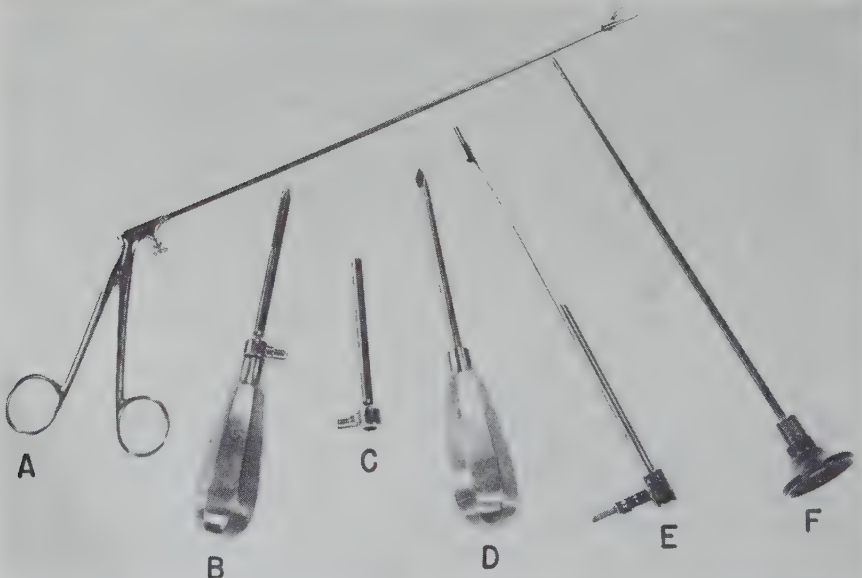


Figure 1. Diagnostic thoracoscope. A, Biopsy forceps. B, C, Trocars, B, D, Diamond obturator. E, Endoscope (Coryllos). F, A foroblique magnifying lens.

tor. Free fluid may then be aspirated completely to permit clear visualization of the pleural surfaces. The endoscopic light carrier is introduced, and the pleura is inspected with the naked eye and through a magnifying lens with slightly oblique orientation.

The second trocar is then inserted at a suitable point visually selected. Inspection may then be carried out through either trocar. With the examiner looking through one trocar, specimens of representative portions of the pleura may be obtained with biopsy forceps inserted through the second trocar. Anesthesia of the pleura may be indicated. If the free pleural space is severely limited by adhesions, it may be necessary to work through one trocar. This requires removal of the endoscope and "semi-blind" biopsy of areas of the pleura that have been visually selected by the endoscope, which must then be removed to permit biopsy through the same trocar.

Almost all nonadherent visceral and parietal pleura may be readily visualized by this technique, and specimens obtained of any superficial lesion of either the visceral or parietal pleura. Wherever localized lesions are observed, single or multiple specimens may be obtained, which may confidently be accepted as representative of whatever pleural condition exists.

At the conclusion of the examination one trocar is removed, and the stab wound is sutured. A suction catheter is then introduced through the remaining trocar and the residual air and fluid are aspirated from the thorax as the trocar and the catheter are removed. The wound is sutured and petrolatum dressings are applied. A roentgenogram is obtained not only to verify that all air and fluid have been removed, but also to visualize the lung for parenchymal lesions which might previously have been obscured by the pleural effusion.

Table 1. *Diagnoses in 50 Cases of Thoracoscopy*

NO. CASES		
Neoplasm		28
Primary		
Mesothelioma	5	
Lymphoma	1	
Metastatic		
Lung	18	
Breast	2	
Ovary	1	
Thymus	1	
Inflammatory		17
Tuberculosis	5	
Pneumonia	3	
Collagenosis	2	
Cause unknown	7	
Miscellaneous		5
Spontaneous pneumothorax	2	
Congestive heart failure	2	
Trauma	1	
TOTAL		50

Diagnosis

The diagnoses established by thoracoscopy, and confirmed by subsequent events, are listed in Table 1. As can be seen, malignant lesions were found in more than half of the cases, inflammatory lesions in one-third, and other conditions in one-tenth. In all 7 patients with inflammatory pleuritis due to unknown causes, complete resolution occurred. Thus, the diagnosis of reactive pleuritis presumably related to underlying pulmonary disease was confirmed.

Complications

There were no deaths attributable to this procedure and no serious morbidity. In 2 patients residual pneumothorax required transient intercostal drainage.

Illustrative Cases

The following cases illustrate clinical application of thoracoscopy.

CASE I. A 35-year-old man came to the Ochsner Clinic because of pleuritic pain on the left side of one month's duration. Three weeks before admission he began to have a hacking, nonproductive cough.

On physical examination decreased breath sounds and decrease in vocal resonance were heard from the tip of the scapula to the base in the left hemithorax laterally, anteriorly, and posteriorly. The tuberculin skin reaction was negative, but the histoplasmin skin reaction was positive. Results of other skin tests for fungi were negative. In the roentgenogram of the chest pleural effusion was demonstrated on the left with a questionable infiltrate in the second anterior intercostal space on the same side.

On thoracentesis an exudate was obtained. Sputa were negative for acid-fast bacilli on smear and culture. At thoracoscopy with use of a local anesthetic a fibrinogenous exudate over the parietal pleural surface was noted. Multiple generous biopsy specimens of the parietal pleura were obtained. The histologic picture of these was compatible with a diagnosis of tuberculosis. Culture of the specimen revealed colonies typical of *Mycobacterium tuberculosis*. The patient responded well to antituberculous therapy, and results of periodic clinical and roentgenographic examinations have been satisfactory.

CASE II. A 63-year-old man sought medical advice because of nonpleuritic pain in the right posterior hemithorax of four months' duration associated with progressive dyspnea. Thoracentesis on two occasions elsewhere yielded fluid which contained no malignant cells or acid-fast bacilli. The patient was thought to have congestive heart failure when referred to the Ochsner Clinic.

On physical examination moderate tachypnea at rest was noted. Decreased vocal resonance and breath sounds were heard from apex to base, most pronounced in the lower third of the right hemithorax posteriorly, laterally, and anteriorly. There was a grade I apical systolic murmur. The rhythm was normal.

Reactions to the tuberculin and fungous skin tests were negative. Sputa for malignant cells and acid-fast bacilli were negative. There was no evidence suggestive of congestive heart failure. On thoracentesis an exudate and cells indicative of, but not diagnostic of, a malignant tumor were obtained.

On thoracoscopy performed with use of a local anesthetic white, irregular, lesions were seen over the visceral and parietal pleura. Multiple generous biopsy

specimens were obtained; the histologic picture was compatible with a diagnosis of primary mesothelioma of the pleura.

DISCUSSION

A correct diagnosis was established by thoracoscopy in 50 consecutive patients with pleural effusion which had been previously undiagnosed. The diagnostic value of the procedure is thus apparent. Its innocuousness is evidenced by the fact that in our series there were no deaths and no serious morbidity.

If the diagnosis of pleural disease with effusion can be established by simple thoracentesis with bacteriologic and cytologic examinations, further diagnostic studies are unnecessary. Blind needle biopsy of the pleura may be attempted with any one of several special needles. If a pleural specimen is obtained containing a typical pathologic lesion, the diagnosis may be established. If, however, a specimen indicative of nonspecific pleuritis is obtained, the presence of disease elsewhere in the pleura cannot be definitely excluded.

Open biopsy with use of a local anesthetic is frustrating because it is extremely difficult to inspect a large portion of pleural surface or to obtain a representative specimen through a short intercostal incision. With general anesthesia and thoracotomy, however, adequate exposure is possible and diagnostic pleural or pulmonary specimens may be obtained. In most instances of pleural effusion, thoracotomy is not indicated for therapy so that the sole indication for this formidable operation is a diagnostic one.

In the presence of a reasonably free pleural space, our experience confirms that of others that thoroscopic inspection and biopsy will establish a correct diagnosis in virtually every case. The one essential is that at least a limited pleural space be present. This condition is met in most patients with pleural effusion. It is important, however, in preliminary attempts to establish a diagnosis by thoracentesis, that no attempt be made to aspirate all the fluid, as this will render more difficult, and perhaps thwart, attempted thoracoscopy.

Diagnostic thoracoscopy has a number of advantages. It is technically simple. It entails minimal operative stress. It permits inspection of a generous portion of parietal and visceral pleura. Such inspection alone may lead to strong suspicion of the correct diagnosis, as for example, the "finger-wave" appearance of pleural mesothelioma. Numerous biopsies of visually selected areas of the pleura representative of typical lesions can be obtained. All pleural fluid may then be removed by catheter without injury to the lung. Finally, complete expansion of the lung may be obtained at the conclusion of the procedure.

Open surgical biopsy was not necessary in any of the patients in this series. All specimens submitted to the pathologist were considered adequate,

and no incorrect diagnoses were made. On the basis of this experience, we now perform diagnostic thoracoscopy earlier in our study of undiagnosed cases of pleural effusion.

CONCLUSION

Diagnostic thoracoscopy has established the correct diagnosis in 50 consecutive cases of pleural effusion, which had remained undiagnosed by other studies. There were no deaths and no serious morbidity. The technique is simple, accurate, and innocuous. It is recommended that this reliable technique, in use for half a century, be more commonly used in the diagnosis of cases of pleural disease with effusion.

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Cancer of the Lung: Recognition and Management

ALTON OCHSNER, JR., M.D.

ALTON OCHSNER, M.D.

The importance of cancer of the lung cannot be overemphasized. Its incidence has increased progressively since the early part of this century, when it was truly a rare disease. Bronchogenic cancer accounts for most cancer deaths in men, and in women it is exceeded only by cancer of the breast, uterus, and colon. This year, 50,000 people in the United States alone will die from cancer of the lung. Almost every physician, with the exception of pediatricians, can expect to see patients with this disease and, if past experience prevails, many will fail to make the correct diagnosis.

RECOGNITION

To diagnose bronchogenic cancer at a curable stage requires a high degree of suspicion because the disease begins insidiously and probably exists for a long time before producing symptoms. Although it is encountered essentially in the older population, one-fourth of the patients have been younger than 50 years of age and several cases in teenagers have been reported.⁴ It is primarily a disease of men, but it is occurring with increasing frequency among women. It is also primarily a disease of smokers. Eighty per cent of epidermoid and undifferentiated carcinomas, including oat cell carcinoma, are probably caused by cigarette smoking.¹⁸ Only adenocarcinoma, which frequently occurs in women, seems to have no relation to smoking.

Symptoms

Bronchogenic cancer has no specifically distinctive symptoms. Symptoms usually result from the *local effect of the primary tumor* on the bronchi or its effect on surrounding structures in the mediastinum, base of the neck, or chest wall. Symptoms also may result from *systemic effects of the primary tumor* (Table 1). Twenty-five per cent of patients have such symptoms

Table 1. *Systemic Abnormalities Associated with Primary Bronchogenic Carcinoma***Metabolic and Endocrine**

Adrenal hypofunction, adrenal hyperfunction, hypercalcemia, hyperestrogenemia, excessive antidiuretic hormone, carcinoid syndrome

Neuromuscular

Cerebral dysfunction, cerebellar degeneration, spinal cord syndromes, peripheral neuropathy (sensory, motor, Guillain-Barré), autonomic nervous system dysfunction, myopathy

Osseous and Connective Tissue

Hypertrophic osteoarthropathy, arthritis, dermatomyositis, scleroderma, acanthosis nigrans

Vascular

Superior vena cava syndrome, thrombophlebitis, Raynaud's phenomenon, non-bacterial thrombotic endocarditis

Hematologic

Anemia, polycythemia, fibrinolytic purpura, cryofibrinogenemia

Table 2. *Symptoms of Bronchogenic Cancer***General**

Fever, chills

Respiratory

Cough, dyspnea, hemoptysis, wheezing, hoarseness

Gastrointestinal

Anorexia, nausea and vomiting, weight loss, dysphagia

Mental

Confusion, irritability, depression, convulsions, coma

Neuromuscular

Weakness, pain (chest, neck and arm, extremity), ataxia, tremor, vertigo, nystagmus, Horner's syndrome, paralysis, numbness, muscle wasting, decreased tendon reflexes

Endocrine

Adrenal insufficiency, Cushing syndrome, gynecomastia

Osseous

Clubbing, swollen painful joints, tender long bones

Vascular and Lymphatic

Supraclavicular and axillary lymphadenopathy, distention of neck and arm veins, thrombophlebitis, Raynaud's phenomenon

Cutaneous and Subcutaneous Tissue

Night sweats, anhidrosis, ecchymosis, pigmentation, flushing, tightness

Hematologic

Excessive bleeding

when first seen. Symptoms may reflect *metastatic disease* to any organ, especially the brain, liver, adrenals, and skeletal system.

Table 2 lists the various symptoms that can occur in patients with bronchogenic carcinoma. Any one of these may be the presenting complaint. These same symptoms might be caused by other conditions, even in the presence of bronchogenic carcinoma. To paraphrase what Osler used to say of syphilis, today we can say of cancer of the lung: A knowledge of the

protean manifestations of this disease is a knowledge of all medicine. This diversity of symptoms indicates the importance of suspecting bronchogenic cancer even in the absence of respiratory signs or symptoms. At the time of diagnosis, most patients have cough (85 per cent), loss of weight (60 per cent), and thoracic pain (58 per cent).⁹ These are obviously late manifestations of the disease. Cough is probably also the earliest symptom, but it seldom leads the patient to an early diagnosis since it may be masked by a pre-existing or what is accepted as a new "cigarette cough." That cough may even be a relatively late manifestation has been suggested by the progressive study of Boucot and co-workers² in which 45 per cent of the patients with bronchogenic carcinoma had roentgenographic signs of the disease before appearance of the cough.

DIAGNOSIS

There is obviously an asymptomatic period in the development of cancer of the lung when, like the proverbial submerged iceberg, it cannot be recognized by presently available diagnostic methods. Every person who has smoked cigarettes for 15 or 20 years should be suspected of harboring such a cancer and deserves to have periodic roentgenography of the chest every three to four months, and a yearly physical examination, even though he is asymptomatic. Although it is not always practical to do so, such a patient would probably also benefit from periodic cytologic examination of the sputum and bronchoscopy. When a smoker has respiratory symptoms, even though the roentgenogram of the chest shows no change, his chances of having bronchogenic cancer have increased. Even if symptoms subside promptly, careful examination including roentgenography of the chest every two months for at least six months is mandatory. If respiratory symptoms persist or recur, whether the patient is a smoker or a nonsmoker, complete pulmonary evaluation is indicated, including thoracotomy if necessary. If results of the other studies are negative and the cause of the symptoms cannot be determined, thoracotomy is not indicated but careful evaluation is, with roentgenography of the chest every two months and complete pulmonary evaluation in six months if respiratory symptoms still persist.

A persistent roentgenographic abnormality of the chest, with or without symptoms, is an indication for complete pulmonary evaluation, including thoracotomy if necessary. If the patient is asymptomatic and has never smoked, and it can be proved that the abnormal pulmonary shadow has existed without change for more than five years, careful periodic examinations including roentgenography without thoracotomy may be justifiable.

Many systemic symptoms (Table 2), even in the absence of respiratory symptoms or roentgenographic abnormalities of the chest, may be due to cancer of the lung. Complete pulmonary evaluation is indicated if these

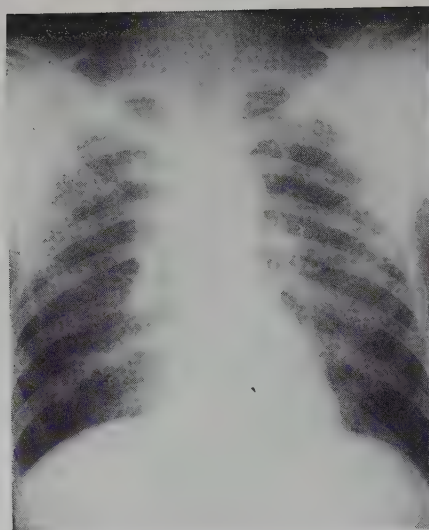


Figure 1



Figure 2

Figures 1-6. Roentgenograms of the chest showing variable patterns of bronchogenic carcinoma.

Figure 1. Lesion in right lower lobe.

Figure 2. Disease of left upper lobe.

persist, even though another diagnosis has been made. This is especially indicated if the patient is a smoker. If no abnormalities are found, roentgenography of the chest at two- to three-month intervals and perhaps complete pulmonary evaluation can be accomplished by many different methods, none of which is infallible and all of which have limitations. Some of these provide a more direct approach to the diagnosis than do others and not all need be used in every patient, although in practice some of them would be employed to determine the extent and resectability of the tumor even after the diagnosis had been established.

The procedures providing a presumptive diagnosis include roentgenography, history (including smoking history), physical examination, and response to medical treatment. A histologic diagnosis will depend on cytologic examination of the sputum, pleural fluid or blood count, or bronchoscopic, scalene node, mediastinoscopic, or thoracoscopic biopsy. Thoracotomy may be required.

Roentgenography of the chest is the most important single investigative procedure for recognizing cancer of the lung. Fluoroscopy of the chest should be part of the radiologic examination, since it provides dynamic information about pulmonary distention, diaphragmatic motion, mediastinal displacement, pleural fluid, and the presence of vascular pulsations in a questionable mass. A lateral roentgenogram, in addition to the postero-anterior projection, is necessary to visualize the pulmonary tissue behind the heart and the mediastinal contents. Inspiratory and expiratory films are valuable in recognizing early bronchial obstruction. Occasionally, a

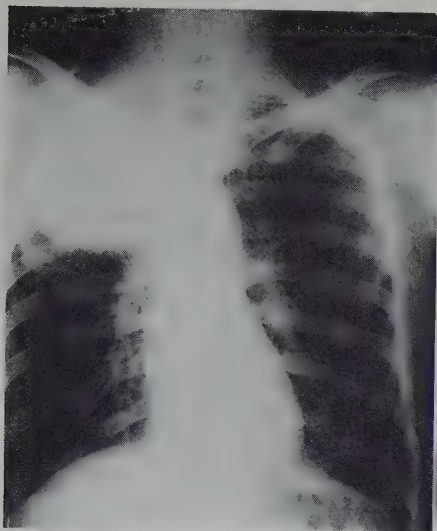


Figure 3

Figure 3. Mass in right upper lobe.

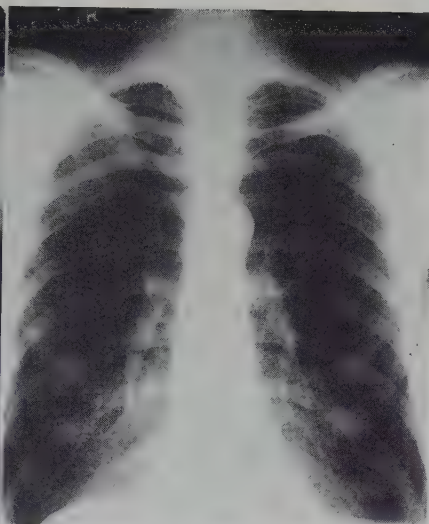


Figure 4

Figure 4. Tumor in right upper lobe, against pleura.



Figure 5

Figure 5. Superior sulcus tumor (Pancoast's tumor).

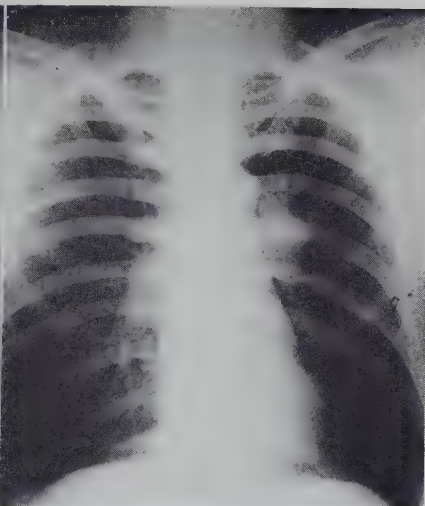


Figure 6

Figure 6. Tumor in left upper lobe near hilum.

lordotic view of the chest is useful for evaluation of a questionable shadow in the apex of the lung. In the presence of suggestive evidence of Pancoast's syndrome, roentgenograms demonstrating bone detail in the upper ribs and adjacent vertebrae should also be obtained.

The roentgenographic picture of carcinoma of the lung can be highly variable (Fig. 1-6). It may resemble any other disease of the mediastinum,

lungs, or chest wall. To be recognized the tumor must be large enough to cast a radiographic shadow or it must be in a position to obstruct a bronchus and produce distal emphysema (partial obstruction) or atelectasis (complete obstruction). The entire roentgenographic shadow may represent regional node metastasis.

The most common roentgenographic pattern is the perihilar mass, which is seen in one-third of the cases. The next most frequent pattern, seen in one-fifth of the cases, is the solitary pulmonary nodule. (One-third of all solitary pulmonary nodules are malignant!). Other roentgenographic patterns include atelectasis, localized emphysema, mediastinal adenopathy, "pneumonic" infiltration or consolidation, abscess or cavity (even of the thin-walled variety), pleural effusion, paralyzed diaphragm, and "apical pleural thickening."

Any roentgenographic shadow in the chest should make the examiner suspicious of cancer of the lung, and he should maintain this suspicion as long as any part of the shadow persists or until it is proved to be something other than bronchogenic carcinoma. Comparison with previous roentgenograms is helpful, although sometimes one sees in retrospect that the tumor had been present but unrecognized for months or even years.¹² With cancer, however, the roentgenographic picture would not remain constant for any prolonged period of time. Even the dramatic clearing of a roentgenographic shadow with antibiotic therapy does not eliminate the possibility of an underlying tumor. Only with vigilant, careful clinical and roentgenographic observation of the patient can this possibly be eliminated. With any residual roentgenographic abnormality, more complete evaluation is indicated.

Bronchography can be particularly useful in the diagnosis of bronchogenic cancer when routine roentgenography fails to visualize the lesion. The bronchographic signs indicative of a malignant lesion have been described: (1) abrupt bronchial obstruction, (2) localized midbronchial displacement or stretching, (3) annular constriction of the bronchial lumen, (4) thumb print indentation, and (5) the "rat-tail" bronchus.⁸

The medical history is important because previous illnesses may be related to the pulmonary trouble under investigation. Patients with previous inflammatory diseases of the lung, such as tuberculosis, or with malignant disease elsewhere, have an increased chance of getting pulmonary carcinoma. Patients with bronchogenic carcinoma commonly give a history of recurrent "atypical pneumonia." The history of malignant disease raises the possibility that the present condition is metastatic,³ but this assumption should not be made without demonstration of other metastatic lesions. Differentiation between primary and metastatic pulmonary disease is not easy. A metastatic tumor, particularly from pancreatic cancer, may involve the bronchus or mediastinal lymph nodes, producing symptoms and laboratory evidence (including demonstration of malignant cells in the sputum) identical to those produced by primary bronchogenic carcinoma.¹³

A history of smoking is extremely valuable in making a presumptive

diagnosis. It is rare for bronchogenic cancer to develop in a nonsmoker, particularly a man. Absence of a history of smoking in a patient with a pulmonary disease is strong evidence against a diagnosis of cancer of the lung. Likewise, every smoker with a pulmonary disease must be considered to have bronchogenic carcinoma until proved otherwise.

Response to antibiotic treatment can be more misleading than helpful. Ordinarily, response to specific therapy is considered one of the best ways to confirm a diagnosis. Unfortunately, in patients with cancer of the lung bronchial obstruction with distal pulmonary infection is common, and a favorable response to antibiotic therapy has probably been the greatest single factor delaying definitive treatment and perhaps cure of these patients. All patients with pulmonary infections should have careful follow-up evaluation even though the infection apparently subsides with antibiotic treatment. This, of course, is particularly true of middle-aged and elderly smokers. Any residual symptoms, roentgenographic abnormality, or recurrence of the pulmonary infection in the same area of the lung demands thorough evaluation designed to eliminate a diagnosis of cancer.

Cytologic examination of sputum can be diagnostic and provides the only positive preoperative diagnosis in approximately one-fourth of the patients with bronchogenic carcinoma. The accuracy of this test depends on the location of the tumor, the method of collecting sputum, the experience of the examiner, and the number of slides examined. Inflammatory cells can be confusing but rarely result in false positive reports. When inflammatory pulmonary disease is suspected, the sputum should be examined for acid-fast bacilli and fungi as well.

Neoplastic cells in the blood are more difficult to recognize, but such an examination may provide the only positive preoperative diagnosis in peripheral cancer of the lung. The blood is taken from a systemic artery, as this is equivalent to the venous drainage from the lung.

Cytologic examination of pleural fluid will frequently establish the diagnosis of pleural effusion due to pulmonary cancer.

Bronchoscopy can provide a direct view and histologic diagnosis of central and lower lobe tumors but its diagnostic usefulness is limited to these. Thus, only one-third of the cases of bronchogenic carcinoma are diagnosed by this procedure.

Scalene node biopsy is only rarely necessary as a diagnostic procedure in cancer of the lung, as almost all patients also have neoplastic cells in the sputum.

Mediastinoscopy is more valuable diagnostically than scalene node biopsy, but like the latter, is used primarily to determine the extent of the disease. It should be employed in patients with a mediastinal mass.

Thoracoscopy with biopsy of pleural lesions can be extremely valuable in tumors associated with pleural effusion. It can prevent thoracotomy.

Thoracotomy is sometimes the only method by which a histologic diagnosis can be established.

Whereas a histologic diagnosis of cancer is always desirable before starting treatment, it should not be considered necessary for suspected bronchogenic carcinoma in the apex of the lung which is producing Pancoast's syndrome (arm and shoulder pain, destruction of ribs, and Horner's syndrome). Paulson,¹¹ who has had the most success in treatment of this tumor, believed that to perform biopsy in this area before irradiation increases the risk of neoplastic dissemination, and trauma of such a biopsy through impairment of vascularity, development of a hematoma, or low-grade infection will decrease responsiveness of the tumor to irradiation. In this special situation the decision for treatment must be based on a clinical diagnosis.

MANAGEMENT

Evaluation of the Patient for Surgery

Bronchogenic carcinoma should be resected, if possible. Whether resection is feasible depends on whether the tumor can be removed and the patient can tolerate the operation.

Resectability of the tumor is determined by the extent of its spread from the primary focus, either directly into contiguous structures or via lymphogenous, hematogenous, and aerogenous routes. Preoperative evidence of direct extension or lymphogenous spread into the trachea or mediastinum may be obtained by bronchoscopy, scalene node biopsy, mediastinoscopy, mediastinal tomography, pneumomediastinography, azygous phlebography, or angiocardiology. Because of the indirect nature of the evidence supplied by the last four procedures, we have employed them only rarely in patients considered borderline operative risks.

Preoperative evidence of hematogenous spread depends on demonstration of metastatic foci, which are most likely to be found in the liver, pleura, lungs, bones, adrenals, kidneys, brain, heart and pericardium, and skin (especially the scalp). Such metastases can be discovered by careful interrogation regarding organ function, and thorough physical examination with selective laboratory studies. Cutaneous, subcutaneous, hepatic and bony masses or areas of tenderness are most significant and deserve further evaluation. The laboratory tests most frequently employed in completion of this evaluation consist of urinalysis, liver function tests, and sometimes hepatic isotope scanning, adrenal function tests, roentgenography of the skeletal system, strontium-85 bone scanning, and electroencephalography. With strong presumptive evidence of hepatic metastasis thoracotomy is probably not justified until abdominal exploration has ruled out this possibility. Adrenal insufficiency does not necessarily indicate adrenal metastasis, as increased plasma corticoids (questionably from the tumor) suggest functional suppression of the adrenal gland.⁷ Abnormal neuromuscular symptoms and signs need not represent disseminated disease but

may be manifestations of neuromyopathies (Table 2), which disappear with successful treatment of the primary tumor.

Existence of bilateral pulmonary malignant lesions does not necessarily mean disseminated disease. It may represent bilateral primary carcinoma or an associated benign lesion.¹⁷ Also, discovery of neoplastic cells in arterial blood is no index of unresectability; metastasis does not develop in all of these patients.

Operative Risk. Whether the patient should be operated on is determined by his general health, his ability to withstand a major surgical procedure, his pulmonary functional reserve, and the limitation of resection imposed by it. In evaluating the operative risk, one cannot ignore the chronologic age of the patient, although age is not a deciding factor. The important considerations are the status of the cardiovascular system (particularly the coronary, cerebral, and renal arteries), adrenal function, hepatic function, circulating red cell mass, and fluid and electrolyte status. Significant disturbances in any of these areas, which cannot be corrected or adequately supported, are contraindications to excision, and irradiation therapy will have to be used.

The patient's pulmonary reserve can be grossly estimated by his ability to walk the length of a corridor briskly and climb stairs without displaying more dyspnea than the physician accompanying him, but this type of estimate may be unfair to the patient and only demonstrates the poor pulmonary reserve of the physician. More precise information is obtained by objective pulmonary function studies, which include blood gases before and after exercise. For accuracy, however, these studies should be done before bronchoscopy, scalene node biopsy, or mediastinoscopy if these examinations are to be done within a few days of each other. If the patient is found to have decreased pulmonary functional reserve, which indicates considerable reduction in the amount of lung that should be resected, management becomes a problem, but in such cases thoracotomy should seldom be deferred, since it is probably better to resect a localized tumor in a less than optimum fashion than to restrict pulmonary function further with irradiation fibrosis. An estimate of the preoperative pulmonary function is desirable, however, so that the patient is not made a pulmonary cripple by the operation.

Surgical Therapy

The indications for pulmonary resection are: (1) tumor localized to the lung; (2) tumor with spread to lymph nodes and contiguous structures, if all the gross neoplastic tissue can be removed and the patient's respiratory reserve is adequate to withstand the magnitude of resection necessary to accomplish this; and (3) palliation of certain symptoms that cannot be controlled by irradiation, such as recurrent pulmonary sepsis or pulmonary abscess due to bronchial obstruction, and massive hemoptysis.

The extent of resection is usually confined to removal of one lobe. It

has been shown that unless the mediastinal nodes are metastatic, pneumonectomy has no advantage over lobectomy.¹⁶ Pneumonectomy is reserved for tumors in the hilum or those that have spread to the hilar and mediastinal nodes. Resection of lesser magnitude than one lobe (segmentectomy) is used for the apical tumor producing Pancoast's syndrome but can also be used to preserve pulmonary tissue in the patient with greatly decreased pulmonary reserve.

Preoperative and Postoperative Care

The success of surgical treatment depends on keeping the patient in optimum physiologic condition during and after operation. Because the very nature of the operation will reduce respiratory function, special attention must be given to the respiratory system. Proper preoperative evaluation of a patient with bronchogenic cancer requires a few days, and this can seem like a frustrating delay, but it is time that can be well used in physiologic preparation. The surgeon must insist that the patient stop smoking, specifically to reduce bronchorrhea. Aerosol inhalation with mucolytic agents is helpful before and after operation. In patients with copious secretions, postural drainage is useful before operation. Prophylactic administration of antibiotics is also desirable. The only advantage attending smoking is that at least smokers know how to cough. It is worthwhile, however, to teach them diaphragmatic breathing preoperatively. Postoperatively, frequent endotracheal suctioning may be necessary if the patient cannot handle his secretions. Sometimes tracheostomy will be required. High concentrations of oxygen are to be avoided, since many of these patients are emphysematous with chronic CO₂ retention.

The cardiovascular system also deserves special attention. Because of their age and smoking most of these patients can be expected to have significant atherosclerotic cardiovascular disease. Reduction in the pulmonary vascular bed (and a relative increase in pulmonary vascular resistance), compensatory shifting of the mediastinum, and the cardiac trauma associated with opening the pericardium may cause cardiac disturbance. In the preoperative period the patient must be kept ambulatory to prevent circulatory stasis and maintain muscle tone. If there are vascular murmurs in the neck, suggesting the possibility of cervical arterial occlusive disease, ophthalmodynamometry should be performed, and if an abnormality is detected, angiography should be done. If severe arterial stenosis is found, prophylactic carotid endarterectomy is justifiable, because in such patients cerebrovascular occlusion can complicate operation of the magnitude of pulmonary resection. If there is a possibility of decreased myocardial reserve, the patient should be treated with digitalis. Cardiac arrhythmia is a frequent problem, which deserves prompt attention. If it follows pneumonectomy, the tension in the operative thoracic cavity should be adjusted. The total circulating blood volume is seldom low preoperatively. In fact, it may be elevated because of water retention from inappropriate secretion of

antidiuretic hormone.¹⁵ This abnormality will be recognized by hyponatremia and hypertonic urine. Management requires preoperative restriction of water. With adequate removal of the pulmonary tumor this should not be a postoperative problem. If the patient is anemic, the circulating red cell mass should be measured with chromium-51, and if low, it should be restored to normal with infusions of packed red blood cells. Normal blood pressure should be maintained in the postoperative period, but multiple transfusions should not be given without central venous pressure monitoring. In these patients the amount of postoperative bleeding can be estimated from the appearance of the roentgenogram of the chest and the blood coming through the intercostal drain.

With the exception of the patient with true Addison's disease and patients undergoing adrenal operations, attention to adrenal function seems to be more important in patients with carcinoma of the lung than in any other surgical patient. Rarely, these patients will secrete an ACTH-like substance which can produce Cushing's syndrome. It is well to recognize these patients, but they should not have any particular difficulty with the operation, and with complete removal of the pulmonary tumor this abnormality should disappear. The important adrenal disturbance to recognize in these patients is the more common functional hypoadrenalism, which can cause postoperative shock and death.⁷ In the absence of chronic renal disease we have found the Kepler water loading test most satisfactory for recognizing these patients. When the result of this test is positive, we prepare the patient with intramuscular injection of 125 mg. of cortisone acetate every 12 hours, for at least three doses followed by 250 mg., intramuscularly, just before the operation. Of course, extra potassium should also be administered. If adrenal function has not been evaluated preoperatively and the patient with bronchogenic cancer is in shock after the operation, adrenal insufficiency should be suspected. To correct this complication, hydrocortisone phosphate rather than hydrocortisone succinate should be used, since it has been our experience that some of these patients are unable to hydrolyze the succinate. Aqueous adrenal extract is perhaps even better, since it also supplies aldosterone.

Adequate renal output must be maintained. Urinary infection should be treated. Since gastric distention, which can produce hypotension, is a common postoperative complication of pulmonary operations, use of a nasogastric tube is recommended for the first 24 hours after operation. Because patients with cancer of the lung may have fibrinolytic disturbances, it is well to examine them for clot lysis.

Radiation Therapy

Radiation therapy is useful treatment of the localized, symptomatic tumor. It is the treatment of choice for a metastatic lesion and can produce dramatic relief of symptoms due to pressure on vital structures, such as the brain, spinal cord, esophagus, or superior vena cava. It is used to treat the

patient with primary bronchogenic cancer only if he cannot tolerate the extent of pulmonary resection required to excise the entire tumor, or when the tumor has spread locally beyond the confines of the lung to the extent that all neoplastic tissue could not be excised. In general, the highly undifferentiated and "oat cell" cancers are the most radiosensitive and the adenocarcinomas the least radiosensitive. The lung, however, is less tolerant of irradiation than many other organs of the body, such as the skin, cervix, and larynx, where epithelial cancers are highly radio-curable.

Preoperative or Postoperative Irradiation

The case for routine preoperative or postoperative irradiation has not yet been proved. Irradiation can certainly be tried to shrink a large mass or control hilar metastases before resection of the tumor. In the case of Pancoast's tumor, the value of preoperative irradiation has been established and has, in fact, converted this previously incurable type of bronchogenic cancer into a potentially curable tumor.¹¹

The experience of Bloedorn and associates¹ suggests that preoperative mediastinal irradiation in all patients with bronchogenic cancer may result in some increase in the resectability and cure rates, but postoperative complications have been more frequent in these patients. For preoperative irradiation a subcancerocidal dose (approximately 3,000 rad) is recommended as it seems to prevent dissemination of neoplastic cells and decreases the viability of cells circulating or spilled without increase in the radiologic or surgical morbidity. Except in patients with Pancoast's tumor, we have only rarely used preoperative irradiation.

Routine mediastinal irradiation after pulmonary resection has not statistically improved the survival rate of patients with bronchogenic cancer.¹⁰ Postoperative irradiation, however, appears to be a beneficial part of definitive therapy when the primary tumor involves the adjacent pleural surfaces (chest wall or aorta), without evidence of nodal metastasis. Under these circumstances, the surgeon should mark with silver clips the area of pleural involvement as a guide to the radiotherapist.

Chemotherapy

Chemotherapy is used for the symptomatic control of metastatic disease. It does not seem to prolong life significantly. Cancer of the lung will often respond favorably to the alkylating agents but antimetabolite drugs have not been particularly effective.¹⁴

Mechlorethamine hydrochloride (Mustargen) has proved to be the most effective drug. It may be given intravenously, intra-arterially, or transpleurally. The dosage is 0.4 mg./kg. of body weight, either as a single dose or in divided doses, but it is best given in the evening to the patient who has fasted for several hours and has been given a sedative or antiemetic premedication because of the frequency of gastric discomfort and nausea. Remission may last from one to several weeks. The highly undif-

ferentiated and oat cell tumors are the most sensitive to the drug. Bone marrow depression may occur but the bone marrow should recover within four weeks, so that repeated injections can be given. The tumor seems to become less responsive to the drug with time. Other alkylating agents which have shown promise in the control of bronchogenic carcinoma are cyclophosphamide (Cytosan), chlorambucil (Leukeran), and benzodepa (Dualar).

Upper hemibody perfusion has been proposed as a method of delivering a greater concentration of chemotherapeutic agents into the chest region while protecting the pelvic bone marrow.²⁰ Effusion (pleural or ascites) can frequently be controlled by the intracavitary instillation of alkylating agents.^{14, 21} Quinacrine hydrochloride (Atabrine) can also be used for this purpose.¹⁹

PROGNOSIS

Incidence of Resectability

When patients with bronchogenic cancer are initially evaluated, approximately 40 to 50 per cent have inoperable disease; in the remainder, exploration is performed with the hope of being able to resect the tumor. Of the latter group, however, only two-thirds have resectable lesions (30 to 40 per cent of the original group). Seventy-five per cent of these should be considered as "palliative" resections, since the tumor has extended beyond the confines of the lung to involve the regional lymph nodes or adjacent structures, such as the chest wall, pericardium, or diaphragm. Only 25 per cent of patients having resection (10 per cent of all patients with bronchogenic cancer) have tumors grossly limited to pulmonary tissue and thus potentially amenable to "curative resection."

Chance of Cure (Five-Year Survival)

The general cure rate in bronchogenic cancer is 6.5 per cent.⁹ Without pulmonary resection the chance of cure is almost nil. A few instances of apparent eradication of the primary tumor by intensive irradiation have been reported, particularly with supervoltage radiation, and some patients receiving only radiation therapy have lived more than four to five years.⁵ A patient with cancer of the lung which is not resected seldom lives more than three years after the diagnosis is made.

With pulmonary resection the five-year survival rate is 15 per cent. It is only 5 to 10 per cent in patients whose tumor has spread to the lymph nodes or contiguous structures (palliative resection). The five-year survival rate increases to 30 to 40 per cent in patients with tumors apparently restricted to the resected pulmonary tissue.

Aside from the obvious extent of the tumor, the prognosis is influenced by sex (better in female patients), age (slightly better in patients younger

than 50 years of age), type of tumor (best with epidermoid carcinoma), and location of tumor (highest with central and upper lobe lesions).

What is the Answer?

More radical surgical excision will not lead to better salvage in patients with bronchogenic cancer. Deaths due to bronchogenic cancer could be reduced by prevention of development of cancer, earlier recognition and resection of primary disease, and development of systemic treatment for metastatic cancer.

It is reasonable to expect that greater awareness on the part of smokers and physicians of the possible existence of bronchogenic cancer and increased use of roentgenography of the chest every three to four months in asymptomatic patients who have smoked 15 to 20 years can lead to earlier diagnosis and thus increase the chance of accomplishing "curative" resection. At least half of the patients are still doomed to die of metastatic disease from hematogenous spread, so that early recognition and treatment are still not the answer. Hopefully, anticancer chemotherapeutic agents which can control systemic spread will some day be developed, but the efforts to date, in spite of large expenditures of time and money, have been disappointing. Any significant decrease in deaths from bronchogenic cancer must come through prevention of the disease. Fortunately, this is possible. Elimination of cigarette smoking could theoretically reduce the incidence of bronchogenic cancer by 80 per cent. It would then no longer be a national health hazard. According to the United States Public Health Reports,¹⁸ a nonsmoker has a 1000 per cent less chance of getting bronchogenic cancer than his smoking companion, but even the latter can significantly reduce his chance of getting bronchogenic cancer by giving up the habit of smoking. For ex-smokers, the probability of getting bronchogenic cancer is directly related to the length of time and amount they have smoked, but is always less than if they continue to smoke. Obviously, the responsible physician must educate his patients about the risk of smoking. The individual himself can do more to prevent his death from bronchogenic cancer than can the surgeon!

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Intrathoracic Neurogenic Tumors

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Neurogenic tumors, though rare, are the most common mediastinal neoplasms.¹⁶ Usually unsuspected until discovered incidentally in routine roentgenograms, or during diagnostic studies for thoracic symptoms unrelated to the tumor, these primary neural tumors are generally located where nerves and ganglia are most abundant—in the posterior mediastinum adjacent to the vertebral bodies. Thirty-two patients with intrathoracic neurogenic tumors were seen at the Ochsner Clinic between 1942 and 1965. The experience is unusual, in that four of them were in areas of the thorax, other than the posterior mediastinum.

CLINICAL FEATURES

Most neurogenic tumors produce no symptoms until they encroach on adjacent structures. Pressure erosion of the vertebra or rib, associated skeletal defects of von Recklinghausen's disease, or intraspinal extension may produce pain as a predominant symptom. Since roentgenography of the chest became routine, most of these tumors are discovered incidentally. When present, pain is usually a dull ache that seldom follows the distribution of the peripheral nerve with which the tumor is related. It may be perceived at a site distal to the tumor and be associated with muscle weakness or other signs of compression of the spinal cord when a large intraspinal component or multiple intraspinal areas are involved.

Compression of the lung produces respiratory symptoms. Wheezing, dyspnea, and persistent cough, occasionally induced by changes in position, are frequently noted complaints. Recurrent attacks of pneumonia are common in children, but pleuritic pain, hydrothorax, and pneumonia seldom occur in adults unless a tumor in the lower half of the thorax compresses a bronchus.

The only symptom specifically related to neoplastic activity is the diarrhea common in children with neuroblastoma.¹⁵ The disturbance in bowel function resembles that of the celiac syndrome, and may be erroneously attributed to that absorptive disorder. The diarrhea associated with neuroblastoma is caused by excess production of catecholamine and disappears with removal of the tumor. Gastrointestinal symptoms in patients with other types of neurogenic tumors are usually unaffected by resection and are probably unrelated to the tumor.¹¹ Many patients with neurogenic tumors seen at the Ochsner Clinic consulted their physician because of tension or anxiety; however, since these are common complaints of patients requesting physical examination, it is difficult to evaluate their relationship to neurogenic tumors but they could result from an excess of catecholamine derivatives.

Signs of von Recklinghausen's disease (café-au-lait spots and multiple subcutaneous neurofibromas) suggest the possibility of intrathoracic neurofibromas, but the preoperative diagnosis of neurogenic tumor depends on roentgenographic demonstration of a smoothly rounded tumor, most often in the midportion of the thorax and located posteriorly in the lateral roentgenogram of the chest.

TYPES

Pathologists generally agree that there are two main groups of neurogenic tumors: (1) those that arise from the nerve sheath cells, the benign neurilemmoma (schwannoma) and neurofibroma, and malignant neurofibrosarcoma or fibrosarcoma;^{1, 16} (2) and those that arise from ganglionic cells of the sympathetic system, the benign ganglioneuroma and malignant neuroblastoma or partially differentiated ganglioneuroblastoma.

CLINICAL MATERIAL

Of the 32 intrathoracic neurogenic tumors encountered at the Ochsner Clinic, 26 were of nerve sheath origin, and 6 originated from ganglionic cells. Two-thirds of the neoplasms were benign and one-third, malignant. The extremes of age were represented, as certain of these tumors have a propensity for specific ages. The youngest patient was 3 years old and the oldest 72 years; 18 were female patients and 14 male.

Nerve Sheath Tumors

BENIGN. Of the 21 benign tumors, 19 were neurofibromas, and 2 neurilemmomas. Others^{1, 10, 13} have reported a higher proportion of neurilemmoma. Schlumberger¹⁶ stated that neurilemmoma is the commonest intrathoracic neural tumor, but that it is usually diagnosed as

neurofibroma by pathologists. He classified as neurilemmoma, tumors with only sheath cells, and as neurofibroma, those with all elements of the nerve trunk. Whether the number of neurofibromas in our series represents a variance in pathologists' interpretation of histologic structure, or is a real difference in patient population, cannot be accurately determined. The tumors do not differ structurally from neurogenic tumors in other parts of the body and, like the peripheral neurofibromas and neurilemmomas, produce no apparent interference with sensory or motor function.

Eleven patients had solitary neurofibromas, located in the posterior mediastinum adjacent to the intervertebral foramen (Fig. 1). The tumor was located in the right thorax in 9 patients and in the left in only 2. Two patients had radiographic evidence of a widened neural foramen. In each the tumor was completely excised.

Four of the 6 patients with multiple neurofibromatosis had bony deformities of erosion of the pedicle, kyphosis, or destruction of ribs (Fig. 2). Two had intraspinal extensions large enough to require laminectomy for excision. Three had bilateral lesions. One of these, with nearly every nerve involved, had had a 160-gram left adrenal pheochromocytoma excised one year before removal of multiple intercostal neurofibromas.

Thoracic neurofibromas generally are manifested earlier in patients with multiple neurofibromatosis.² Five of our 6 patients with multiple neurofibromatosis were younger than 35 years of age when operated on. In

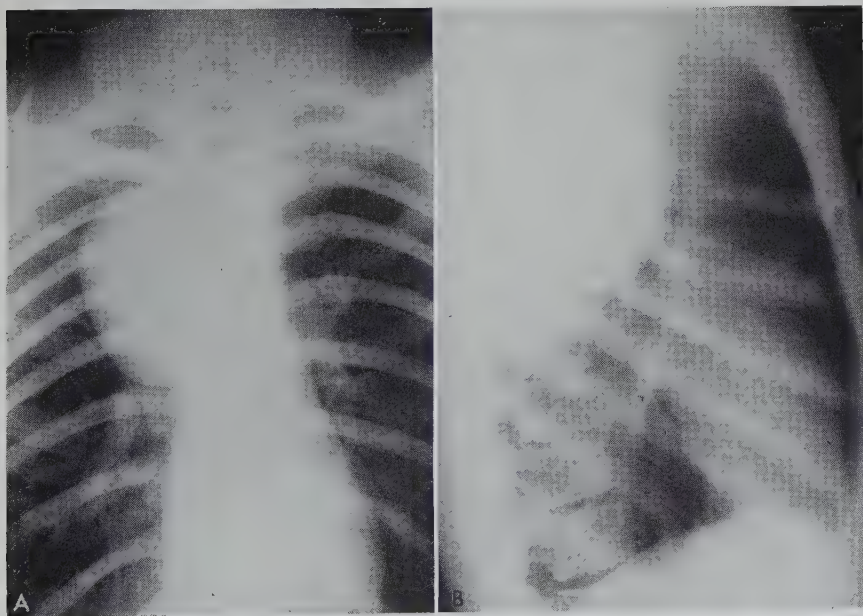


Figure 1. Neurofibroma. A smooth, uniformly dense, rounded tumor with sharp border. (A) Acute angle with mediastinum and (B) location in posterior mediastinum are characteristic.

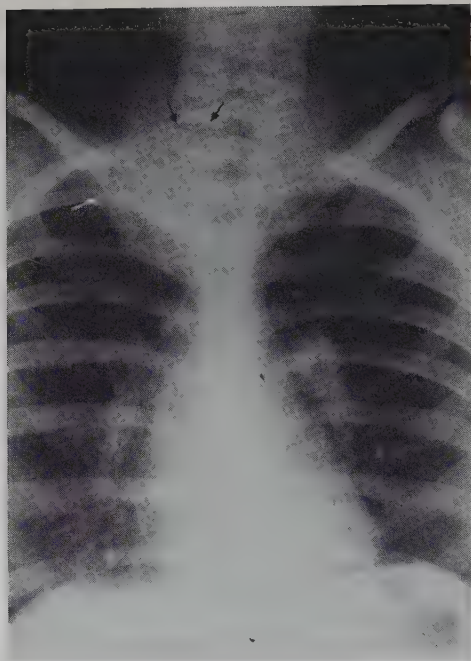


Figure 2. Neurofibroma. Vertebral changes with neural tumor. Erosion of rib and neural foramen occurs in benign and malignant tumors.

contrast, most patients with solitary neurofibroma or neurilemmoma are between 40 and 60 years of age when seen. Only 2 of our 11 patients were younger than 35 years of age when operated on. Three patients had benign intrathoracic nerve sheath tumors located outside of the posterior mediastinum. One patient had a neurofibroma 6 cm. in diameter growing inward from the left third intercostal nerve at the costochondral junction anteriorly. Two patients had neural tumors of the left vagus, just below the origin of the recurrent laryngeal nerve. One of these proved to be a neurilemmoma and the other a neurofibroma.

Benign neurofibromas do not recur after excision and, except for the patient with the neurofibroma of the costochondral junction who died of pulmonary embolus after excision, all of our patients with solitary lesions are well. Patients with von Recklinghausen's disease, on the other hand, run a continual risk of getting additional neurofibromas, which frequently involve the spinal canal. There is no direct evidence that these neurofibromas become malignant, but one of our patients with neurofibrosarcoma had had benign neurofibromas excised before we saw her with the malignant tumor.

Two patients had intrathoracic neurilemmomas (see Fig. 3). One of these originated from the left vagus nerve, and the other arose from the right first intercostal nerve posteriorly.

MALIGNANT. Five patients had intrathoracic neurogenic sarcomas (neurofibrosarcoma, malignant schwannoma) (see Fig. 4). Two were women with von Recklinghausen's disease, and both had had excision of neurogenic

tumors previously. One patient had had a benign neurofibroma excised four years before; laminectomy was required for removal of the interspinal component of the tumor. The patient is living two years after resection of the mediastinal mass. In the other patient an apparently independent, low-grade neurofibrosarcoma of the thigh had been removed by amputation 15 months before resection of a left superior-posterior mediastinal neurofibrosarcoma. The patient died three months after resection. Two other patients with posterior mediastinal neurofibrosarcoma had no evidence of von Recklinghausen's disease. Both had lesions which could not be completely resected and both died within a few months of operation. The fifth patient with neurogenic sarcoma is one of the 4 patients we have seen with intrathoracic neurogenic tumors outside of the paravertebral gutter. This patient had a neurogenic sarcoma 5 cm. in diameter that completely occluded the right middle lobe bronchus. Four years after initial resection, metastatic neurogenic sarcoma was excised from the right breast, and ten years after the initial operation, a metastatic tumor, which histologically resembled neurofibroma, was biopsied from supraclavicular nodes. The patient is apparently well 11 years after the original operation. The change from frankly malignant to apparently benign tumor resembles that seen in some patients with neuroblastoma, and suggests that recurrent neurogenic

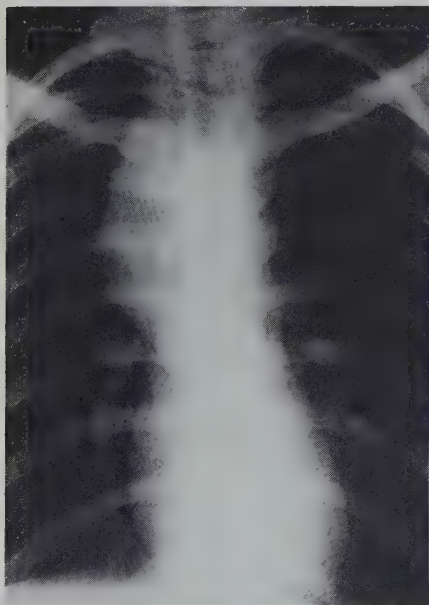


Figure 3

Figure 3. Neurilemmoma. The smooth, sharp bordered tumor frequently is fusiform and meets the mediastinum at an obtuse angle.

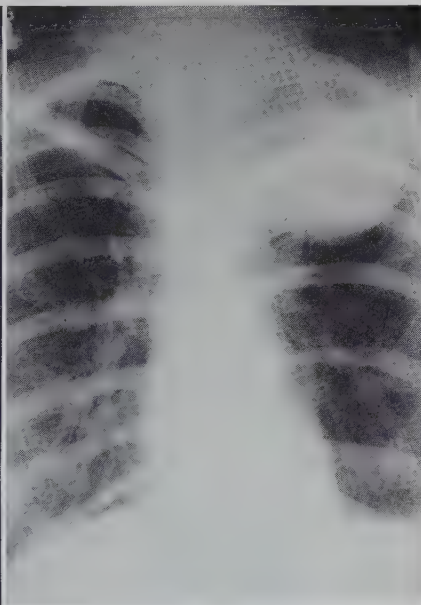


Figure 4

Figure 4. Neurogenic sarcoma. Not clearly distinguishable from neurofibroma, but outline is often less distinct.

tumors should be excised whenever possible, as long-term survival may follow.

Pain is common in patients with neurogenic malignant tumors. Thoracic pain was the dominant symptom in all of our patients. The duration of pain ranged from two months to two years, and in the 3 patients with intraspinal extension, it was associated with motor impairment.

Sympathetic Ganglionic Tumors

These tumors, which originate from sympathetic nerve cells, frequently have demonstrable neuro-endocrine activity manifested by diarrhea or other intestinal disturbance and measured by increased excretion of catecholamines in almost all patients with neuroblastoma and in some with ganglioneuroma.⁹ In addition to benign ganglioneuroma and malignant neuroblastoma (Fig. 5), ganglioneuroblastomas with both benign and malignant elements may be seen. Intrathoracic sympathetic ganglionic tumors are encountered in female patients more often than in males and have a predilection for the right side. Neuroblastomas are the most common solid tumors of childhood,¹² but are more commonly located outside the thoracic cavity.

Since the adrenal glands contain the largest amount of chromaffin tissue, they are the most common site of neuroblastomas. The tumors in the

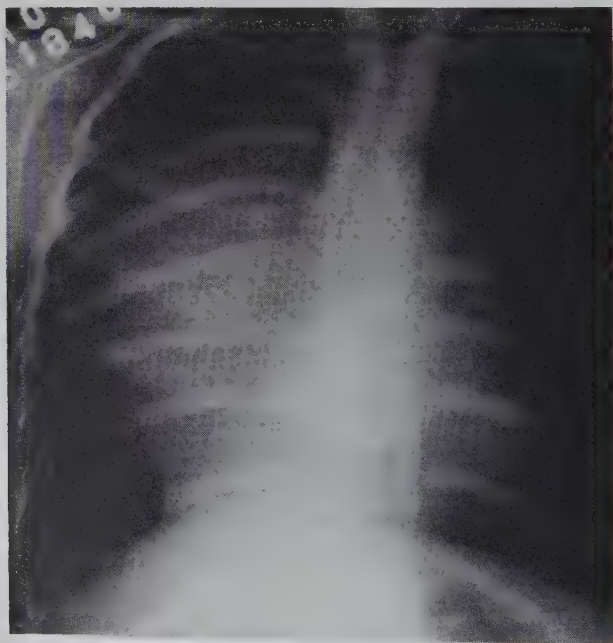


Figure 5. Neuroblastoma. The indented lateral surface suggesting lobulation is frequently seen. Note angulation of vertebral column.

chest are usually not resectable by the time they are discovered, and death within a few months is common.

Of 5 patients with intrathoracic neuroblastomas, all but one were girls. The exception was a man, aged 57 years, whose entire mediastinum on the right was involved with tumor that responded well, but briefly, to roentgenotherapy. He died nine months after diagnosis. The children were aged 3, 4, 6, and $7\frac{1}{2}$ years at the time of diagnosis. The girl, whose left-sided tumor was resected at the age of $7\frac{1}{2}$ years, had no evidence of the tumor when coarctation of the aorta had been repaired three years previously. The only long-term survivor, whose left mediastinal tumor had been removed at the age of 4 years, was alive with recurrence in the sacral canal at the age of 14 years, having had three recurrent lesions excised. The recurrent lesions had relatively little differentiation when compared with the original tumor. On the other hand, we have seen 2 patients with retroperitoneal neuroblastomas who had recurrences with progressive differentiation to benign tumors.

All children with intrathoracic neuroblastomas had dyspnea, recurrent pneumonia, bronchitis, and fever. None complained of diarrhea, though several patients with retroperitoneal neuroblastoma seen at this institution have had diarrhea.

Only one patient in our series had a ganglioneuroma, a woman aged 29 years, who had been delivered of a viable infant nine months before excision of the tumor. Most patients with ganglioneuroma are younger than 30, the majority being in late childhood or their teens.^{1, 4, 10} Unless the tumor excretes significant amounts of catecholamines, it produces no symptoms. These tumors do not recur after resection.

TREATMENT

The primary indications for removal of neurogenic tumors are prevention of restriction of pulmonary function, avoidance of compression of the spinal cord, and the possibility that the tumor is malignant. Management begins with preoperative evaluation of the patient's physical condition, with particular attention to whether the tumor has produced skeletal deformity,⁸ especially if a neurofibroma is suspected. Careful radiologic evaluation of the spine, particularly by means of planigrams to determine the size of the intervertebral foramen, is necessary. An enlarged intervertebral foramen strongly suggests intraspinal extension of the thoracic tumor and myelography should be performed. Myelograms will indicate whether there is an intraspinal tumor, or rarely, will demonstrate that the tumor is a meningocele, rather than the solid tumor suspected.⁶ It may be possible to remove small intraspinal tumors through the thoracic incision at the time the thoracic component is excised. Large tumors usually must be removed in

two stages; it is preferable to remove the spinal component first. The benign tumor can be divided in the intervertebral foramen without concern.

At thoracotomy, the tumor characteristically is found behind the pleura, usually in the sulcus between the rib and the vertebral body, but its exact position depends on its size. Its blood supply usually comes from the intercostal artery in the segment from which it arises, and venous drainage is into the azygos system. The azygos vein usually must be sacrificed because the tumor is often located at the entrance of the azygos vein into the superior vena cava.

The postoperative course is seldom complicated. Though spinal fluid may escape into the thoracic cavity for the first few days after resection of the intraspinal extension of a neurofibroma, meningitis or even persistent headache has not developed in any of our patients.

DISCUSSION

The most interesting aspect of these tumors is their origin. Only neuroblastomas are common in children; however, ganglioneuromas are the most common neurogenic tumors in youths. Neurofibromas predominate in adulthood.

Though most neuroblastomas are fatal, some recur repeatedly and then disappear, or each recurrent tumor develops more highly differentiated tissue, finally becoming a ganglioneuroma which, when resected, does not recur. This differentiation invariably occurs before puberty. The neuroblastomas that become manifest after puberty do not differentiate and usually are rapidly fatal. Beckwith and Perrin³ reported microscopic neuroblastomas at necropsy in the adrenals of 0.5 per cent of infants younger than 3 months of age. All but one had an associated congenital anomaly, usually cardiovascular. A cardiovascular anomaly, aortic coarctation, was present in one of our patients with a neuroblastoma.

The hormonal activity of these tumors has been extensively studied.^{5, 7, 9, 15, 17} Almost all patients with neuroblastomas, and some with ganglioneuromas, have increased excretion of catecholamine derivatives. This excess hormonal production probably accounts for the diarrhea and mild hypertension that occur in these patients. The presence of these tumors in many neonates, their hormonal activity, association with congenital anomalies, differentiation into benign tumors before puberty, and their rarity in adulthood suggest that the tumors result from persistence of fetal activity, probably as the result of an enzyme deficiency which can be compensated for after birth, either by diet or other endocrine activity.

The history and associated problems of patients with neurofibromas or neurilemmomas are extremely different. Neurilemmomas develop in persons 25 years of age or older; if they recur, they are malignant. The associated anomalies in patients with von Recklinghausen's disease are varied

and may involve any system. Though neurofibromas have not been demonstrated to have significant hormonal activity, pheochromocytoma developed in one of our patients with multiple neurofibromatosis. Robinson¹⁴ pointed out the discrepancies in the neural crest theory of origin of neurofibromas and concluded that neurofibromatosis results from disturbance of biochemical systems upon which the gene of the disorder works its effect. His concept appears reasonable, particularly when compared with the probable relationship to other neurogenic tumors. It is probable, however, that the enzyme deficiency in neurofibromatosis is different from that of neuroblastoma. There is some indication that the enzyme defect may be expressed nutritionally rather than genetically. If this is the case, these tumors will probably become increasingly uncommon. Their careful study may give answers to many problems related to tumorigenesis.

SUMMARY

Intrathoracic neurogenic tumors may become manifest at any age. Neuroblastomas are common in children, ganglioneuromas in youth, and neurofibromas, neurilemmomas, and neurofibrosarcomas in adults. These tumors are usually asymptomatic, single, and almost always located in the posterior mediastinum. Of 32 patients with primary intrathoracic neurogenic tumors seen at the Ochsner Clinic, 4 had tumors outside the posterior mediastinum.

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Tumors of the Thymus

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Thymic tumors comprise about 10 per cent of mediastinal neoplasms.³⁰ It has been suggested that from a practical standpoint they should be classified as noninvasive and invasive.^{21, 30}

The function of the thymus is poorly understood. According to Miller,²⁴ some Greeks considered the thymus to be "the seat of the soul." In 1902 Beard² asked, "has it yet fallen to the lot of any writer upon the thymus to write the truth and be believed?" The truth is that the function of the thymus is still unknown but there has been considerable speculation concerning the purpose of this gland.

Undoubtedly, the thymus is greatly concerned with immunologic reactivity. Miller²⁴ reported normal development, life span, lymphocyte population in blood and tissue, and ability to reject foreign skin grafts of normal mice, in mice whose thymuses had been removed at birth and within one week thymuses from newborn donors had been grafted (in contrast to those not grafted). With donors of the same strain as the host, all foreign grafts were rejected. With donors of different strains the host usually showed some tolerance to grafts of thymus donor-type skin, but not to third party skin grafts.

ASSOCIATED CONDITIONS

The thymus has also been implicated in *aplastic anemia* and *hypogammaglobulinemia*. In 1962, Dreyfus and associates⁹ collected 47 cases of thymoma and associated hypoplasia of the erythroid elements of the bone marrow, analyzing 43 of these and 2 of their own; 13 patients had associated leukopenia or thrombocytopenia. In 41 collected and 2 personal cases of refractory anemia associated with thymoma, Roland²⁷ found that thymectomy was more successful in producing remissions than conservative

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therapy. Of 22 patients treated by thymectomy, 8 had remissions, whereas among those treated conservatively only 2 had remissions. Chapin⁶ reported hypogammaglobulinemia in a patient with thymoma, which was biopsied at operation but not removed. Conservative therapy produced a remission for three months, but subsequently, the patient died. Godfrey¹² mentioned association of benign thymomas with plasma cell aplasia (agammaglobulinemia) and bone marrow aplasia (aplastic anemia) in an identical twin. Hinrichs and associates¹⁸ reported the case of a man, aged 47, with myasthenia gravis, thymoma, and aplastic anemia who died from intracranial hemorrhage on the fourth day of hospitalization. Recently, Demos and co-workers⁸ reported a case of megaesophagus in a 46-year-old woman who also had an 8 by 7 by 7 cm. benign thymoma, which was successfully removed. They suggested the possibility of common metabolic derangements as well as etiologic relationship between the two conditions.

Myasthenia Gravis

The most important systemic condition associated with the thymus is myasthenia gravis. Wilson and Wilson³¹ reported that thymic extracts exert a depressing effect on muscular contraction in nerve-muscle preparations. Laquer and Weigert²⁰ in 1901 first reported association between malignant thymic neoplasm and myasthenia gravis. In 1900 Grandhomme¹⁴ suggested the name thymoma for thymic neoplasms. In 1908 Meggen-dorfer²³ also reported a malignant thymic tumor associated with myasthenia gravis.

In 1913 Schumacher and Roth²⁸ reported a case of a 21-year-old girl with severe hypothyroidism and myasthenia gravis in whom, on roentgenography, a mass, thought to be an enlarged thymus, was visualized in the anterior mediastinum. The right superior thyroid artery and vein were ligated, but little improvement resulted. At a second operation the thymus, which weighed 49 grams, was removed. It was hypertrophied and resembled a fetal thymus but there was no true neoplasm. The myasthenia gravis was greatly improved but the patient was not cured. Eighteen months later subtotal thyroidectomy was followed by a severe crisis from which she recovered. This is apparently the first case in which thymectomy was done in the treatment of myasthenia. There is some question, however, whether it was done primarily for the myasthenia or the hyperthyroidism, because at that time in Germany hyperthyroidism was thought to have a definite relationship to thymic activity. We are inclined to believe that the thymectomy was done primarily to influence the hyperthyroidism. The patient's improvement was probably accidental. In 1917 von Haberer¹⁶ reported improvement in a 27-year-old man with myasthenia gravis after partial thymectomy, although there was no evidence preoperatively of thymic enlargement. Three years later the patient was still improved.

Bell³ collected 56 cases of myasthenia gravis observed at necropsy. The thymus was enlarged in 17 of the patients, and in 10 others it contained a

tumor. He concluded from this observation that some form of thymic involvement seems to occur in nearly half the cases of myasthenia gravis. Bell described thymic tumors associated with myasthenia gravis as comparatively small, benign growths, composed of young thymic tissue, many of which are hemorrhagic. He collected 75 reported cases of thymic tumors not associated with myasthenia gravis.

In 1937 Adler¹ reported a case in which Sauerbruch removed a thymic tumor of considerable size with a fatal outcome eight days later of mediasinitis. The same year Obiditsch²⁶ reported another case operated on by Sauerbruch. The thymic tumor was the size of a man's fist. The patient died five days postoperatively from a streptococcic infection.

Lievre²² reported postmortem studies on 67 patients with myasthenia gravis; in 24 a tumor was found in the thymic area; 32 had persistent or hypertrophied thymuses and 11 had no abnormalities. Norris²⁵ believed that pathologic changes may be found in the thymuses of patients with myasthenia gravis in direct proportion to the care with which they are sought. Of the 35 cases he studied (including those previously reported by Bell), 18 were classified as enlarged thymuses and 18 as tumors. He believed that in reported cases of myasthenia gravis with associated benign tumors of the thymus, the thymic lesion was in reality extreme epithelial hyperplasia and not a neoplasm.

In 1939 Blalock and associates⁵ reported a case of severe myasthenia gravis in a girl 19 years old with roentgenographic evidence of a sharply circumscribed mass in the anterior-superior mediastinum. Roentgenotherapy reduced the size of the mass but subsequently the symptoms became worse and roentgenography showed that the mass in the anterior mediastinum had enlarged. Roentgenotherapy failed to relieve symptoms. An apparently necrotic benign thymic tumor was removed. At the time the case was reported the patient had had no symptoms for the preceding two years. The patient had been incapacitated for months every year for four years but during the three years after removal she had had only one mild recurrence, associated with severe respiratory infection, which lasted only a few days.

Keynes's¹⁹ first case was a young patient with severe myasthenia gravis, a nodular goiter, and mild thyrotoxicosis, which necessitated operation. Both the thymus and thyroid were removed. The postoperative course was severe, but in a few months the patient improved, and at the time of the report, had been well for 11 years. Keynes has become an ardent protagonist of thymectomy for myasthenia gravis; of 33 patients with myasthenia treated by thymectomy, 60 per cent were well or greatly improved, 24 per cent somewhat improved, and 15 per cent no better. Later in an additional 120 cases these respective figures were 65.8 per cent, 25.8 per cent, and 8.3 per cent. These were patients seen up until 1949. Since 1949, 200 additional patients with myasthenia gravis without thymomas were

studied. Of these, 100 were carefully studied by Ross; 70 per cent had excellent results from thymectomy or were greatly improved.

Seybold and associates²⁹ found myasthenia gravis in 34 of 45 patients with thymoma (75 per cent). Conversely, only 15 per cent of their patients with myasthenia gravis had thymic tumors. Bernatz and associates⁴ reported that only 46 per cent of 138 patients operated on at the Mayo Clinic for thymic tumors had myasthenia gravis. Also, 70 per cent of those without myasthenia gravis had no symptoms from the tumors.

Keynes¹⁹ stated that not more than 15 per cent of myasthenic patients have thymic tumors, but their plight is much more serious than the other 85 per cent without tumor. The initial results of primary removal of thymic tumors were so bad that Keynes decided to try high voltage roentgen-ray therapy instead of primary operation. Of 41 patients with thymic tumors, all the earlier ones treated surgically were dead, but of the 26 treated first with deep roentgen ray, 20 had subsequent removal of the tumor, and 4 of these were quite well (14 per cent). Three patients who had only deep roentgen-ray therapy were also well. Keynes stated that roentgen ray cannot be relied upon to destroy all the cells of the thymoma unless a dangerously high dosage is given. For this reason, operation should also be done when circumstances permit. Of 7 patients with thymoma treated by roentgen ray, Legg and Brady²¹ reported best results in 2 who received the least irradiation.

TREATMENT AND PROGNOSIS

There is considerable speculation concerning the prognosis in thymic tumors. Bernatz and associates⁴ stated that myasthenia gravis presents "far more dangers to the immediate success of the operation than any imposed solely by the thymic tumor." They reported a five-year survival rate of 23 per cent for invasive tumors and 80 per cent for noninvasive tumors among 138 patients. The five-year survival rate for the entire group was 63 per cent. Forty of their patients had invasive tumors and 4 of their 6 hospital deaths were in this group. The five-year survival rate of patients with thymoma and without myasthenia gravis was 62.5 per cent, and of those with myasthenia gravis, 63.8 per cent. Of the 64 patients with myasthenia, 28 per cent were definitely improved. In the patients with myasthenia gravis without thymic tumors, 68 per cent were benefitted by thymectomy, which is somewhat better than those with thymic tumors (63.8 per cent). On the basis of their experience, Bernatz and associates recommended an aggressive attitude toward thymic tumors whether or not myasthenia gravis is associated.

Based on study of the cases at the Mayo Clinic and a comparative study of the cases reported by Keynes and from the Johns Hopkins Hospital, Eaton and co-workers¹⁰ noted a diversity of opinion regarding the

advisability of thymectomy in the treatment of myasthenia gravis. Keynes is an ardent advocate of thymectomy, whereas Eaton and associates¹⁰ concluded that a relationship exists between myasthenia gravis and the thymus gland, but the thymic abnormalities probably do not cause myasthenia gravis. Removal of non-neoplastic thymus glands in young female patients leads to remission of the symptoms of myasthenia gravis, which they attributed probably to altered metabolic process.

In 1935 Decker⁷ collected 206 cases of malignant tumors of the thymus and reported 2 of his own. He stated that carcinoma of the thymus will be fatal unless the growth can be successfully removed. However, he believed that roentgenotherapy is successful in many cases of lymphosarcoma of the thymus.

Effler and McCormack¹¹ reported 19 cases of neoplasms of the thymus, 6 of which were associated with myasthenia gravis. Treatment of the neoplasm did not appear to benefit the myasthenia gravis in any of the patients. Of the 19 patients, 16 had malignant lesions, in 10 of whom there was direct extension of the malignant tumor; 4 had pleural implantation, one recurrence, and one distant metastases. Most authors assume that thymic tumors, even when malignant, do not metastasize, but Effler and McCormack had a case with metastasis to submaxillary lymph glands. They believed that thymic tumors are malignant or potentially malignant and that the danger of malignant change is of greater importance than any possible relationship with myasthenia gravis. They also did not consider treatment of myasthenia to be the primary indication for operation in thymic neoplasm. Biopsy alone was done in 3 of their patients, excision of the tumor in 9, and irradiation in 10.

Grob's¹⁵ experience shows that patients with myasthenia gravis can often be treated by nonsurgical methods. Of 202 patients with generalized myasthenia gravis observed for an average of eight years, 46 had complete or nearly complete remission, the longest lasting 17 years with an average of 4 years. Forty-four (19 men and 25 women) were subjected to thymectomy from two to twelve years previously (with an average of six years).

Generally, the patients subjected to thymectomy had more severe disease than those not operated on. Nine of the 44 had thymomas. The results of irradiation in 40 patients or thymectomy in 44 patients were only slightly better than in those treated conservatively. They considered myasthenia gravis associated with thymoma usually to be a severer type of disease which offers a poorer prognosis than when thymoma is not present. Of 9 patients with thymomas 6 died with myasthenia gravis; 4 of the patients not operated on had a rapid, fulminating, deteriorating course terminating in death; postmortem examination showed thymoma.

Legg and Brady²¹ reported 51 cases of thymoma, of which 38 were associated with myasthenia gravis and 13 were not. The mean age for the former was 50 years, and for the latter 42. Of 13 with myasthenia gravis, the myasthenia was thought to be the cause of death in 7 patients. Of 36

patients with noninvasive tumors, 32 had excision and 4 irradiation. Eighteen survived at least five years and an additional 10 were alive at the end of the study from one to four years. Four died between the sixth and ninth years, one of myasthenia gravis and one of unrelated causes. There were five deaths in the first year and two at three years. Of the 10 with invasive tumors, 7 were treated solely by roentgen ray after biopsy, 2 had irradiation after attempted extirpation. Four of the 10 survived five years after therapy, and 2 others were alive at one and a half and two years. One died at five years of myasthenia gravis and respiratory infection. The five-year survival rate for the entire group was 61 per cent. Of the 7 patients treated with roentgen-ray, 5 had good results.

In making a diagnosis of thymic neoplasm, Harper and associates¹⁷ advocated erect posteroanterior and lateral roentgenograms of the chest and a coned lateral view of the anterior mediastinum, which should be underpenetrated. Tomography was apparently of no value because in none of their patients in whom tumor was not visible on the posteroanterior or lateral view did tomography show it. Tomography was, however, of value in demonstrating the extent of the mass. The lateral film showed no abnormality in only one patient with an extremely small tumor. They also believed that amorphous or diffuse calcification is suggestive of a thymic tumor. In 51 cases reported by Legg and Brady,²¹ a mediastinal mass was discovered by routine roentgenography in 20. In 34 patients with thymoma and myasthenia gravis, Seybold and associates²⁹ reported preoperative diagnosis of the thymoma in 33. Good¹³ was able to make a diagnosis of thymic tumor by roentgenography in 33 of 206 cases of myasthenia gravis. In 8 of these the findings were so characteristic that they considered there was no doubt about the diagnosis although it was not proved. In 20 it was proved by operation and in 4 by necropsy. In only one was it not definitely proved.

Between 1944 and 1965 we saw 27 patients with thymic enlargement and 56 patients with myasthenia gravis, 4 (7 per cent) of whom had thymic enlargement (2 benign thymomas, one malignant thymoma, and one hyperplasia). These 4 were all women; the ages of the women with thymoma were 30, 40, and 54 years respectively, and the one with hyperplasia was 32 years. Of the 27 patients with thymic enlargement, 14 were males (51.5 per cent) and 13 females (48.5 per cent). The median age and average age in both groups was 32 years with extremes of 6 months and 69 years. Of the 27 with thymic enlargement, 4 had myasthenia gravis (14 per cent); the diagnosis was confirmed at operation in 24, at necropsy in 2 (one benign and one malignant), and by supraclavicular node biopsy on one (malignant thymoma).

Of the 24 patients operated on, 8 had biopsy only and 16 excision of the tumor. Of the 27 patients with thymic enlargement, 14 had malignant lesions and 13 benign. Of the 20 patients with thymomas, 12 had malignant and 8 benign tumors. Nine patients had roentgenotherapy and 6 chemotherapy.

Two other patients had both irradiation and chemotherapy. Of the 16 patients whose tumors were excised, 3 had malignant tumors (2 thymomas, one lymphosarcoma). Six other patients with malignant tumors (5 malignant thymomas and one lymphosarcoma) had only biopsy.

Of the 15 benign lesions 13 were excised, of which 8 were thymomas, 3 hyperplasia, one vascular hamartoma, and one thymic cyst. The other 2 patients had only biopsies. Of the 16 patients whose tumors were excised, 9 are apparently well, one with a malignant tumor and 8 with benign tumors. One patient with a malignant tumor established by biopsy had roentgenotherapy followed six weeks later by excision and died three months later. We have been unable to obtain followup data on 5 patients with benign tumors. Of the 8 patients who had only biopsy, 6 had malignant tumors, 3 of whom are well after roentgenotherapy. Four patients died, 3 with malignant tumors and one with a benign tumor; the patient with the benign tumor died immediately after the operation, while being turned on the operating table, from cardiac arrest. One patient, treated with nitrogen mustard, was last seen six months after the beginning of therapy and is presumed to be dead. Of 9 patients treated by irradiation 7 had malignant tumors and 2 had benign tumors. Of these 6 are well, 4 with malignant and 2 with benign tumors. Three, all with malignant tumors, died.

Six patients were treated with nitrogen mustard. Three of the 5 with malignant tumors are well, and the other 2 are dead. The patient with benign tumor was seen six months after the beginning of therapy at which time the mediastinal mass had enlarged; we have been unable to follow this patient further and presume he is dead. The longest survival after surgical extirpation is 9 years in a patient whose thymoma was removed, and the longest survival after roentgenotherapy and nitrogen mustard is 14 years, in a patient with malignant thymoma.

The incidence of associated myasthenia gravis in our patients with thymic enlargement (14 per cent) is less than that of most reported series. The patient with the malignant thymoma had had symptoms of myasthenia gravis for 11 years; four years previously roentgenography of the chest revealed no abnormality but at the time of admission right pleural effusion was present. After evacuation of the fluid, nodular shadows were visible in the anterior portion of the right hemithorax. On thoracoscopy several masses measuring 3 to 4 cm. in diameter were visible in the anterior mediastinum. On biopsy these were malignant lymphomas. The patient was treated with nitrogen mustard followed by cobalt therapy with no benefit. Of the 3 with benign lesions all were benefitted, one very much so over a 7½-year period; the other 2 require less medication than before operation, one having been followed 5½ years but the other only 8 months. As has been reported by others, thymic tumors are frequently malignant. Actually, slightly more than one-half of our patients (14 of 27) had malignant tumors.

The ideal treatment of thymic tumors, and thymic enlargement, is

extirpation whenever possible. Frequently, because of invasion the tumor cannot be removed. In two-thirds of our 24 cases excision was possible, whereas in one-third⁸ only biopsy was done. Since many thymic tumors are radiosensitive, however, particularly those with a large lymphoid component, the disease is not necessarily hopeless. Results of extirpation are better than results after other methods of therapy or simple biopsy. Also, there was a high percentage of recoveries in patients with benign lesions which were excised (13 of 15).

Nine patients are well after excision (one with a malignant tumor and 8 with benign tumors) out of 16 who had excision. Of the 8 on whom only biopsy was done, 3 are apparently well, all with malignant tumors; 4 are known to be dead, and the other one, who could not be traced, is also probably dead.

Our experience as well as that of others indicates that thymic enlargement occurring after infancy is of significance. If associated with myasthenia gravis, it is particularly significant because removal of the thymus can benefit many of these patients. It has been our experience, as well as that of others, that most patients with associated thymic enlargement and myasthenia gravis are more likely to have a benign lesion than a malignant one. Of our 4 patients with thymic enlargement and myasthenia gravis, 2 had benign thymomas, and one malignant hyperplasia. Three had excision and one was treated with nitrogen mustard.

Although it has been repeatedly emphasized that thymic tumors, even the malignant ones, do not metastasize generally, this is not necessarily true because one of our patients with a malignant tumor had metastasis to the regional lymph nodes and to the diaphragm. Of the malignant tumors, however, most of them are nonresectable and the cure rate is low because of the local invasion of the tumor which prohibits its complete removal. In all patients with malignant tumors which are not removed, irradiation should be used, alone or combined with chemotherapy. Both of these methods of treatment are beneficial.

SUMMARY

Thymic lesions are rarely encountered in persons past early life. Such neoplasms comprise only 10 per cent of all mediastinal tumors. Their association with aplastic anemia, hypogammaglobulinemia, thyroid disease, and myasthenia gravis has been reported. There are three types of thymic lesions: hyperplasia, benign tumors, and malignant tumors. Myasthenia gravis is more often associated with benign hyperplasia or thymoma than with malignant lesions. Many patients with severe myasthenia gravis are benefitted by thymectomy. The best treatment of thymic tumors is extirpation, but irradiation is of value if removal is impossible. Our experi-

ence includes 27 patients with thymic lesions and 56 with myasthenia gravis, 4 (7 per cent) of whom had enlarged thymuses.

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Tumors of the Chest Wall

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Tumors of the chest wall can involve the soft tissues or the thoracic skeleton.⁹ The two types are usually not difficult to differentiate except when a soft tissue tumor is extensive and fixed to the underlying tissues or a bone tumor is associated with extensive reaction in the overlying soft tissue. The tumors may be benign, primary malignant, or metastatic. In addition, there are a large number of non-neoplastic conditions which may simulate chest wall tumors, either clinically or roentgenologically.

TUMORS OF THE THORACIC SKELETON

Though less common than tumors of the soft tissues, tumors of the thoracic skeleton represent a more serious problem because most of them are malignant. In fact, the most common tumor of the thoracic skeleton is a metastatic lesion, and sometimes it is the first sign of the primary neoplasm. The primary tumors are most frequently in the lung, breast, or prostate. Metastatic tumors usually cause pain but some are first discovered on roentgenography of the chest.

Primary tumors of the thoracic skeleton may be benign (Table 1) or malignant (Table 2), the former being slightly more common. They can be loosely grouped according to origin as cartilaginous and osteogenic or hematopoietic and reticuloendothelial. Tumors of cartilaginous origin predominate. The most frequent benign tumors are osteochondromas, fibrous dysplasia (which is probably not a true neoplasm but deserves to be listed with them), eosinophilic granuloma, and hemangioma. The most frequent primary malignant tumors are myelomas and chondrosarcomas. Tumors are found most often in the ribs and least often in the sternum but with surprising frequency in the scapula. Benign tumors are especially rare in the sternum, primary malignant tumors are unusual in the thoracic vertebra,

Table 1. *Benign Thoracic Skeletal Tumors*

CARTILAGINOUS AND OSTEOGENIC	HEMATOPOIETIC AND RETICULOENDOTHELIAL
Osteochondroma	Fibrous dysplasia
Enchondroma	Eosinophilic granuloma
Chondroblastoma	Nonosteogenic fibroma
Chondromyxoid fibroma	Hemangioma
Bone island	Lymphangioma
Osteoma	Aneurysmal bone cyst
Osteoid osteoma	Bone cyst
Osteoblastoma	Lipoma
Giant cell tumor	Cholesteotoma
Ganglion cyst	Myxoma
Xanthoma	

Table 2. *Malignant Thoracic Skeletal Tumors*

CARTILAGINOUS AND OSTEOGENIC	HEMATOPOIETIC AND RETICULOENDOTHELIAL
Chondrosarcoma	Myeloma
Osteogenic sarcoma	Hodgkin's disease
Parosteal osteogenic sarcoma	Reticulum cell sarcoma
Malignant giant cell tumor	Ewing's tumor
	Malignant giant cell tumor
	Fibrosarcoma
	Angiosarcoma
	Liposarcoma

and metastatic tumors are uncommon in the scapula. The primary tumors of the thoracic skeleton are usually symptomatic when first discovered; more than 60 per cent of benign tumors and more than 85 per cent of malignant tumors are symptomatic.⁸ The initial manifestation of benign tumors of cartilaginous and osteogenic origin is five times more frequently a mass than it is pain, but when the tumors are of hematopoietic and reticuloendothelial origin pain is twice as common as the presence of a mass. In primary malignant bone tumors of cartilaginous and osteogenic origin pain and mass are seen with almost equal frequency, but primary malignant tumors of hematopoietic and reticuloendothelial origin are manifested almost exclusively by pain alone.⁸

Diagnosis

The diagnosis of thoracic skeletal tumors may be obvious from the classic roentgenographic appearance but frequently it is difficult to make. Many factors must be considered.

AGE AND SEX. Benign tumors are usually found in young adults, primary malignant tumors in middle-aged persons, and metastatic tumors in the elderly.⁸ Thoracic skeletal tumors have a predilection for male pa-

tients. Osteochondromas (or osteocartilaginous exostoses) are usually seen in boys, enchondromas in women, osteblastomas in adolescent boys, and bone island tumors in women. Chondrosarcomas are most common in men and osteogenic sarcomas in adolescent boys. Fibrous dysplasia is seen in middle-aged men and women, aneurysmal bone cysts in boys, eosinophilic granuloma in boys and girls, myeloma in men, and reticulum cell sarcoma and Hodgkin's and Ewing's sarcoma in adolescent boys and girls.

SYMPTOMS. The essential complaints of patients with thoracic skeletal tumors are pain and a mass. There is nothing typical about the pain. It is usually in the region of the tumor but a vertebral or posterior rib tumor may cause intercostal neuralgia. Discomfort is often vague and diffuse but sometimes severe, localized, and associated with point tenderness. Osteoid osteoma characteristically produces nocturnal pain. A large tumor may exist but not be clinically apparent because of its location deep beneath the thick muscles under the scapula or intrathoracically. A pulsating tumor is diagnostic of metastasis from carcinoma of the thyroid or a hypernephroma.²

The average duration of symptoms of primary malignant tumors is more than twice that of benign lesions, and for cartilaginous and osteogenic tumors more than eight or nine times that of hematopoietic and reticulo-endothelial tumors. In our experience⁸ the average duration of symptoms of benign tumors was more than one year, of primary malignant tumors a few years, and of metastatic tumors only a few months. We had one patient with a chondrosarcoma of the sternum with symptoms for fourteen years before curative resection.

MALIGNANT TUMOR ELSEWHERE. The history or discovery of a malignant tumor elsewhere may lead to recognition of the metastatic nature of the thoracic skeletal tumor. Unless, however, the patient has multiple tumors, one should not assume that the tumor in the chest wall is metastatic, and further diagnostic procedures are indicated.

ROENTGENOGRAPHY. Roentgenography can be invaluable and sometimes is diagnostic (bone island). Often, however, it is of only limited value and sometimes it is misleading.⁸ Special views and techniques with attention to bone detail are essential. Oblique films and planigrams are helpful. Intraosseous phlebography may be informative.⁶

OTHER LABORATORY PROCEDURES. Studies, such as blood count, urinalysis, serum calcium and phosphorus determinations, acid and alkaline phosphatase determinations, and bone marrow examination, have limited diagnostic value. Radioactive strontium 85 is sometimes useful in localizing tumors that cannot be visualized in routine radiographs.

BIOPSY. The only definitive diagnostic procedure is biopsy, and whenever feasible, this should be excisional. Interpretation of the true histologic appearance of a cartilaginous tumor in particular can be extremely difficult, the difference between a benign cartilaginous tumor and a low grade chondrosarcoma is often slight.⁷ Curettage may be necessary for vertebral

tumors which cannot be excised. Rarely, needle biopsy of an obviously metastatic tumor is justified.

PERIODIC EXAMINATIONS. The correct diagnosis may depend on careful periodic examinations, because what was originally thought to be a "benign" tumor of the thoracic skeleton can prove in time to have been malignant.⁸

Treatment

Tumors of the thoracic skeleton should be completely excised when possible. This is recommended even for metastatic tumors, when open biopsy is necessary, for it provides the quickest relief of symptoms. If a primary malignant tumor is suspected, the excision should be wide. Wide excision of tumors of the ribs means as much of the rib as possible because of propensity for intramarrow¹² and periosteal⁴ spread of these tumors, the rib above and below, and the adjacent pleura and overlying muscles. For tumors in the lower portion of the sternum, all of the sternum except the manubrium must be removed, including the adjacent costal cartilages. When the manubrium is involved, the medial heads of the clavicle should also be excised. Large defects in the thoracic wall can be bridged by Marlex, fascia lata, rib struts, or when low and lateral on the chest, by elevation of the lateral attachment of the diaphragm. Wide excision of the clavicle means the entire bone and surrounding muscles; sometimes it is necessary to resect the adjacent ribs as well. For primary malignant tumors of the scapula forequarter amputation is indicated for high grade malignant disease, and for low grade malignant disease, *en bloc* excision dividing the upper humerus and clavicle, preserving a functional arm.^{1, 3} Resection of vertebral neoplasms is limited to those involving the spinous and transverse processes and pedicles. Tumors of the body of the vertebra must be treated by curettage followed by irradiation.

For synovial sarcoma at least regional lymph node excision is also desirable, because this tumor has a higher incidence of spread to the lymphatics than any other sarcomas of the chest wall. In any part of the chest wall local recurrent lesions should be excised when feasible, as re-excision may provide a cure.⁸

Irradiation can be an adjunct to surgical excision or it can be used in the treatment of obvious metastatic disease, but in general it should not be employed as a primary treatment for tumors of the thoracic skeleton unless consent for operation is refused or the tumor is surgically inaccessible. Some tumors are highly radiosensitive: reticulum cell sarcoma, myeloma, Ewing's tumor, hemangioma, and eosinophilic granuloma. Endocrine therapy and chemotherapy have a place in the management of metastatic tumors, particularly of the breast and prostate.

Prognosis

The prognosis of benign tumors of the thoracic skeleton is good but

cartilaginous tumors sometimes recur,⁸ a fact which underscores the importance of periodic examination of these patients for a long time. The prognosis of malignant tumors depends on the type. It is extremely poor for metastatic tumors and primary malignant tumors of hematopoietic and reticuloendothelial origin but relatively favorable for malignant tumors of cartilaginous and osteogenic origin, particularly chondrosarcomas. Most of these patients are hopefully cured after radical surgical excision.⁸ The prognosis is less favorable, however, for osteogenic sarcomas and synovial sarcomas.

SOFT TISSUE TUMORS

As in the thoracic skeleton, tumors of the soft tissue of the chest may be benign or malignant, primary or metastatic. Primary tumors of the somatic soft tissues are more common and metastatic tumors are less common than those in the bones and cartilages.

Although neoplasms in this anatomic area are sometime histologically undifferentiated, most of them have definite histogenesis. They may arise from any of the tissue types in the chest wall: epithelial, fibrous, adipose, muscular, vascular, reticuloendothelial, nerve, and undifferentiated tissue (Table 3). Except for breast tumors and cutaneous nevi, lipoma is the most common benign and fibrosarcoma the most common malignant soft tissue neoplasm found in the chest wall.⁹ Metastatic tumors are most commonly from the breast, stomach, uterus, and kidney.

Pain is an unusual symptom of tumors of the soft tissues. It usually is the result of pressure on a nerve. The small, subcutaneous nodule of a leiomyoma or a glomus tumor (which is rare in the chest wall) may be exquisitely tender, however. The presenting complaint of patients with soft tissue tumors of the chest wall is usually a painless mass but sometimes it is skin discoloration (nevi and hemangiomas) or discomfort on movement of the shoulder girdle. The tumor, especially neurofibromas, may be recognized first by its intrathoracic projection on roentgenography of the chest. The mass can be of any size. It is usually superficial and moveable, but may be extensive and fixed to the bone or other deep tissues. Sometimes the tumor ulcerates, becomes infected, and bleeds.

Diagnosis

As with tumors of the thoracic skeleton when the diagnosis is not obvious, many factors should be considered:

AGE AND SEX. Vascular tumors are usually seen in female infants and children, fibrosarcomas and neurofibroma in young adults, lipomas in middle-aged women, but liposarcomas in men.

CLINICAL FEATURES. Vascular tumors are soft, whereas fibrous tumors are firm and adipose and muscle tumors are of variable density. A

Table 3. *Soft Tissue Tumors of Thoracic Wall*

BENIGN		MALIGNANT
Epithelial		
Epidermal	Verruca Keratosi Nevus Cyst	Squamous cell carcinoma Basal cell carcinoma Melanoma
Adnexal	Breast tumors Tumors of sebaceous, apocrine, and eccrine glands	Breast tumors Tumors of sebaceous, apocrine, and eccrine glands
Fibrous	Fibroma Desmoid Dermatofibroma	Fibrosarcoma Dermatofibrosarcoma protuberans
Adipose	Lipoma Hibernoma	Liposarcoma Malignant hibernoma
Muscle	Leiomyoma Rhabdomyoma Granular cell myoblastoma	Leiomyosarcoma Rhabdomyosarcoma Malignant granular cell myo- blastoma
Vascular	Hemangioma Lymphangioma Glomus tumor	Angiosarcoma Kaposi's sarcoma Hemangiopericytoma Lymphangiosarcoma
Reticuloendothelial		Lymphoma Lymphosarcoma Reticulum cell sarcoma Hodgkin's disease Mycosis fungoides
Peripheral nerve	Neurilemmoma Neurofibroma Ganglion neuroma	Malignant neurilemmoma
Undifferentiated	Myxoma Mesenchymoma	Myxosarcoma Malignant mesenchymoma

tension cyst may even be hard. Fibrous tumors (including neurofibromas) do not transilluminate light well whereas most of the others do. If the tumor is intrathoracic or beneath the muscles, it may not be palpable. With muscle contraction, submucosal tumors become more difficult to feel and intramuscular tumors become less mobile.

ROENTGENOGRAPHY. Roentgenography is of limited usefulness in the diagnosis of soft tissue tumors compared with skeletal tumors. Intrathoracic extension, soft tissue swelling, bone erosion, or calcification may, however, be demonstrated in roentgenograms.

OTHER LABORATORY PROCEDURES. These are primarily indicated to rule out conditions other than soft tissue tumors. As with skeletal tumors, the diagnosis is best established by excisional biopsy. For extensive tumors, needle biopsy may be used.

PERIODIC EXAMINATIONS. Periodic examinations are important, especially if the patient has multiple benign lesions, for malignant transformation may occur in some (neurofibromas).

Treatment

It is wise to excise all large or growing benign tumors. A cavernous hemangioma in infants should be observed, however, because even though initially this tumor enlarges, in time spontaneous involution usually occurs. Malignant soft tissue tumors require wide excision unless they are obviously multiple as is frequently the case with Kaposi's sarcoma and lymphomas. Wide excision of muscle tumors means the entire muscle group because there may be multicentric tumors and there is a tendency to spread along fascial planes. If the skin is involved, it should be widely excised. The defect can be closed by split thickness skin graft or rotation of skin muscle flaps. The adjacent thoracic skeleton should be resected as well when the soft tissue tumor is attached to the periosteum. The regional lymph nodes should be excised with vascular malignant lesions and fibrosarcomas but this is less important for malignant tumors of adipose or muscle origin. An apparent solitary pulmonary metastatic lesion should not deter the surgeon from wide resection of a primary fibrosarcoma but the pulmonary lesion should also be resected.⁹

Irradiation is not a substitute for surgical excision except in far-advanced disease. It can be an adjunct to surgical excision, given postoperatively and even preoperatively, especially in extensive lesions, for it may reduce the size of the tumor so that resection becomes possible.¹¹

The prognosis of benign tumors of the soft tissues is good but must be guarded in malignant tumors even after radical excision because of the propensity of some of the soft tissue tumors for hematogenous spread.

CONDITIONS SIMULATING THORACIC WALL TUMORS

A number of conditions of the thoracic soft tissues and thoracic skeleton (Table 4) may simulate thoracic wall tumors. Some of these cause confusion only clinically, and others (as indicated by the asterisks) roentgenographically.

The hypertrophied costal cartilage is probably the condition most frequently referred for evaluation, but in babies, infantile cortical hyperostosis is most confusing because its roentgenographic appearance can be mistaken for osteogenic sarcoma. Myositis ossificans is important not only because it resembles sarcoma from the clinical and radiologic standpoint but, also because it may even undergo malignant change.¹⁰ A septic temperature is not always helpful in differential diagnosis of chest wall tumors and infections because some neoplasms, notably Ewing's tumor, may cause such fever. Conversely, the temperature response of some infections is masked by antibiotics. Tietze's syndrome (questionably a real entity) is a painful, suppurative swelling of the sternoclavicular or costochondral joint.⁵ The second costochondral junction is most frequently involved.

Table 4. *Conditions Simulating Thoracic Soft Tissue and Skeletal Tumors*

	SOFT TISSUE TUMORS	SKELETAL TUMORS
Normal anatomic relationships—misinterpreted	Breast,* nipple*	Center of ossification,* prominent xiphoid
Congenital abnormalities	Polythelia, polymastia, anomalous muscle	Hypertrophied costal cartilage, pigeon breast, rib anomalies,* infantile cortical hyperostosis*
Post-traumatic conditions	Foreign body, hematoma, myositis ossificans,* fat necrosis	Fracture, costochondral separation
Infections and inflammations	Granuloma, pseudo-epitheliomatous hyperplasia, specific infections, abscess, empyema necessitans, nodular non-suppurative panniculitis	Osteomyelitis,* osteochondritis,* hydatid cyst,* arthritis, gout
Circulatory disturbances	Aortic or intercostal artery aneurysm, thrombophlebitis of chest wall vein	Aseptic necrosis,* spontaneous absorption of bone,* rib notching*
Nutritional and metabolic disturbances	Amyloidosis, calcinosis, xanthoma tuberosum	Rickets, scurvy, hypervitaminosis A, sprue*
Endocrine disturbances	Gynecomastia, cystic mastitis	Hyperparathyroidism,* acromegaly
Collagen disorders	Dermatomyositis, periarteritis nodosa	
Conditions of unknown etiology		Paget's disease of bone,* melorheostosis,* Caffey's disease,* osteopoykilosis,* Tietze's syndrome

* Conditions important from the standpoint of radiographic interpretation.

CONCLUSIONS

Tumors of the chest wall may involve the soft tissue or the thoracic skeleton. The latter type is frequently malignant. Chest wall tumors can be difficult to diagnose. They can be simulated by a large number of conditions. Excisional biopsy is recommended. Wide excision of primary tumors is the treatment of choice, and in many such malignant tumors, the prognosis seems favorable. Resection is well tolerated. Because correct histologic diagnosis of cartilaginous tumors, particularly, can be difficult, careful periodic examinations are recommended even for "benign" tumors. Resection is recommended for locally recurrent tumors.

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Management of Esophageal Tumors

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Esophageal neoplasms continue to challenge the diagnostic and therapeutic acumen of surgeons. Results of surgical management of benign tumors have been acceptable, but results of treatment of malignant tumors have been disappointing. The voluminous publications on management of esophageal malignant disease emphasize the difficulties encountered in treatment and inadequacies of results. This report is based on our experience with 137 patients with esophageal tumors seen at the Ochsner Clinic from January, 1942, to January, 1964. The distribution of cases according to histologic type is shown in Table 1. Excluded from this study were cases of esophageal cysts, paraesophageal tumors, adenocarcinoma of the cardia of the stomach, carcinoma of the pharynx, and metastatic or invasive carcinoma of adjacent organs.

Table 1. *Distribution of 137 Esophageal Tumors According to Histologic Type*

HISTOLOGIC TYPE	NO. OF PATIENTS
Benign	
Leiomyoma	9
Lipoma	1
Hemangioma	1
Malignant	
Squamous cell	110
Anaplastic	6
Adenocarcinoma	1
Leiomyosarcoma and squamous cell	1
No histologic diagnosis	8
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BENIGN TUMORS

Benign esophageal tumors are rare. Among 11,000 patients with dysphagia at the Mayo Clinic, only 15 had benign esophageal tumors.¹⁶ These lesions are encountered most often in older men, although they have been found in persons of all ages.

Anatomically, benign tumors of the esophagus may be classified into mucosal or intraluminal and extramucosal or intramural types. Included in the intraluminal group are polyps, lipomas, fibromas, and myxomas. Leiomyoma, the most common benign esophageal tumor, and the rarely encountered hemangioma are examples of the extramucosal or intramural group. The mucous membrane, usually intact over these lesions, may ulcerate. Although solitary as a rule, these tumors occasionally are multiple.

Clinical Manifestations

Benign esophageal tumors seldom produce symptoms unless their size causes obstruction or annular constriction occurs. Dysphagia is the most frequent symptom; two-thirds of the patients in our series had dysphagia. Other gastrointestinal symptoms include vomiting, regurgitation, anorexia, loss of weight, hematemesis, and melena. Cough, dyspnea, wheezing, or recurrent infections of the upper respiratory tract may be produced by compression of the tracheobronchial tree by the enlarging tumor. Aspiration may be produced by esophageal obstruction. Three patients in our series had substernal or epigastric pain. Symptoms may develop suddenly or insidiously, or they may appear intermittently. These tumors usually grow slowly and may attain large size without producing symptoms. Three patients in the present series were asymptomatic.

Diagnosis

Esophagoscopy and esophagography are the two most useful diagnostic aids. The intramural tumor is demonstrated roentgenographically as a sharply outlined, round or oval, filling defect, which forms a sharp angle with the adjacent uninvolved esophagus in contrast to a sloping angle produced by extrinsic lesions impinging on the esophagus. The polypoid intraluminal tumor is more difficult to visualize roentgenographically. It is frequently difficult to visualize by esophagoscopy, because it may be pushed out of view by the advancing esophagoscope but other hindrances are the intact mucous membrane and the location of the tumor. In one reported series 25 per cent of the tumors were not visualized at esophagoscopy.²⁸

Treatment

Treatment is surgical removal in all except those considered extremely poor surgical risks because these tumors occasionally undergo malignant change. Moreover, they may become so large as to produce esophageal

obstruction with resultant cachexia or respiratory compression. Pedunculated tumors also have been reported to produce respiratory obstruction and asphyxia when regurgitated. The polypoid intraluminal tumor may be removed with a snare through the esophagoscope. Occasionally, their pedicle contains large vessels, which bleed excessively. Larger polypoid lesions require thoracotomy and esophagotomy for removal.

Most intramural lesions can be removed transthoracically by enucleation. Since the mucous membrane is usually intact over these tumors, it is seldom necessary to enter the esophageal lumen. Annular or large tumors frequently require resection of the involved portion of the esophagus. In our series extramucosal enucleation of leiomyomas was done in 4 patients, and in 2 the involved segment of the esophagus was excised. One patient refused surgical treatment. The remaining 2 leiomyomas were found incidentally at necropsy. The lipoma was removed by open excision through a thoraco-abdominal incision. There were no postoperative complications. One patient with an extensive cavernous hemangioma, which was biopsied endoscopically, has had repeated endoscopic examinations for one year. The tumor has remained innocuous and unchanged morphologically.

Results

Most patients experience complete relief of symptoms after removal of the tumor. Motility studies indicate some characteristics of cardiospasm in patients who continue to have symptoms, which may be due to changes resulting from prolonged dilatation of the esophagus proximal to the tumor.⁴ All our patients obtained complete symptomatic relief.

MALIGNANT TUMORS

CARCINOMA

Carcinoma is the most common and most important type of esophageal tumor. It is reported to be the fourth most common malignant lesion in men older than 20 years of age.¹⁰

The etiology is unknown, but chronic trauma to the esophagus appears to be an important underlying factor. Alcohol, tobacco, spicy foods, and poor oral hygiene with inadequate mastication are all sources of chronic trauma. The much higher incidence of this disease in oriental countries has been attributed to the drinking of large quantities of extremely hot tea. The incidence is greatly increased in patients with Plummer-Vinson syndrome. The highest incidence occurs between the sixth and eighth decades of life. Eighty-five per cent of our patients were in this age group (Fig. 1). The patients ranged in age from 26 to 82 years. Males are affected more often than females. The ratio of men to women in our series was

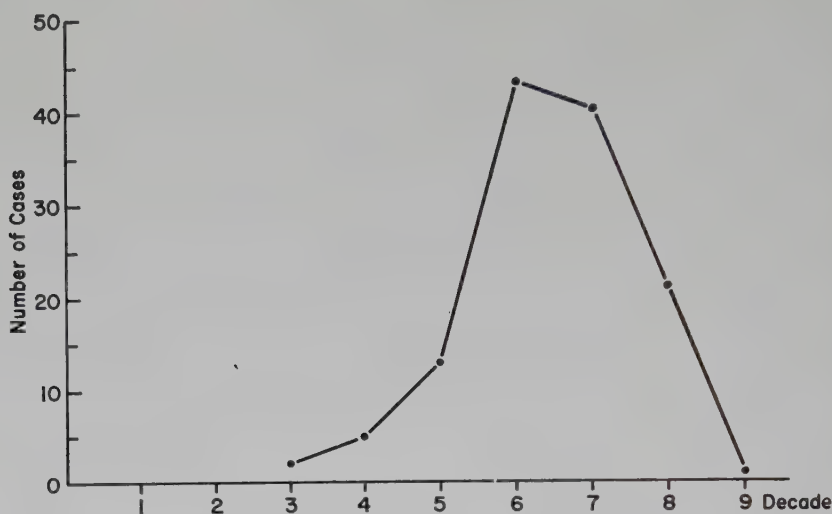


Figure 1. Distribution of 125 cases of carcinoma of the esophagus according to age.

2.2:1 (86 men and 39 women). This is in agreement with other reports. Ratios as high as 7:1 have been reported, however.²⁴

From a therapeutic and prognostic standpoint the location of the tumor is extremely important. One-fourth of the tumors in our series were located in the upper third, distribution in the middle and lower thirds being equal. The middle third of the esophagus is involved most frequently in most reported series.

Clinical Manifestations

Dysphagia is the most frequent symptom. It was the initial and predominant symptom in 93 per cent of our patients. Because of narrowing of the esophageal lumen by the tumor, dysphagia usually is a late symptom and may even be absent in patients with far-advanced lesions. Substernal pain is a relatively common symptom that is due to esophageal narrowing or invasion of the periesophageal nerves. Hoarseness is produced if the tumor encroaches on the recurrent laryngeal nerve. Hematemesis is usually mild, although massive gastrointestinal hemorrhage has been reported in the absence of dysphagia.⁶ Other symptoms are substernal pressure hiccough, respiratory difficulty, and foul breath.

Patients usually have symptoms six to eight months before seeking medical advice. In our series the duration of symptoms ranged from two weeks to eight years with an average of six and one-half months. There is no correlation between the duration of symptoms and the resectability of the tumor or the survival rate.³⁰

Physical findings do not contribute materially to early diagnosis. Loss of weight may be due to insufficient food because of dysphagia or to the systemic response to the tumor. Hepatomegaly, a palpable abdominal or

cervical mass, ascites, and vocal cord paralysis usually indicate incurable metastatic disease.

Abnormal results of laboratory tests are few. The hemoglobin and hematocrit values were below normal in only 15 per cent of our patients, and with two exceptions the depression was mild. The infrequency of anemia may be a false negative sign attributable to hemoconcentration secondary to prolonged malnutrition and dehydration. The erythrocyte sedimentation rate, however, was elevated in 72.7 per cent of our patients. Serum proteins are usually normal or slightly depressed until the late stages of the disease.¹¹ Production of ACTH by hepatic metastasis was recently reported.¹⁵

There are four gross forms of carcinoma of the esophagus. The most common form is a bulky, fungating, cauliflower type. The overlying mucosa is usually friable and ulcerating, and frequently becomes infected or bleeds. The next most common is the infiltrative form, which may appear annular or "napkin ring." The mucosa often is intact over this lesion. The other basic types, the polypoid and ulcerative forms, are rare. The first two types produce symptoms relatively early, whereas the rarer types cause symptoms late.

Histologically, most carcinomas are squamous cell. In our series there was one adenocarcinoma, which arose in the middle third of the esophagus from heterotopic gastric mucosa.³ Most squamous cell carcinomas are grade II to grade IV. Apparently, however, there is no correlation between histologic grade of the tumor and incidence of metastasis or survival rate.^{21, 26} Takahashi,²⁶ however, recently reported good correlation between the degree of stromal inflammatory cell infiltration and the prognosis.

Diagnosis

Esophageal carcinoma must be differentiated from hiatus hernia with or without esophagitis, benign tumors, diverticula, stricture, and achalasia. Unless special circumstances prevent it, all patients with suspected tumors should have both esophagography and esophagoscopy. These two examinations provide diagnostic information in more than 90 per cent of patients. The roentgenographic appearance varies with the type of gross lesion but, in general, an irregular, rigid mass with a proximal shelf encroaching on the lumen of the esophagus is visualized. Depending on the degree of obstruction of the lumen, there may or may not be proximal dilatation of the esophagus. An infiltrating lesion may appear as an area of stenosis which closely resembles a benign stricture. Occasionally, carcinoma appears as a benign ulcer or severe esophagitis. In the early stages there may be no roentgenographic changes.¹

Sometimes, esophageal carcinomas are difficult to visualize at esophagoscopy, especially infiltrative tumors which may have an intact mucosa over them. Multiple biopsies should be performed since 10 to 20 per cent of the initial biopsy specimens yield negative results.²¹ Friability of the mucosa

and alterations in the esophageal motility may be the only indications of underlying disease.

Treatment and Prognosis

Torek²⁷ performed the first successful thoracic esophagectomy in 1911. After resection of the tumor in the middle third of the esophagus, he exteriorized the cervical segment and connected it to a gastrostomy by means of a long rubber tube. The tumor did not recur. In the ensuing years, however, other surgeons have not been as successful as Torek. The result was development of an extremely fatalistic attitude regarding this disease. Much of this pessimism exists today, and with just cause.

The poor prognosis of carcinoma of the esophagus is due to three factors. The first is the advanced age of the patient. Old people have a much higher incidence of concomitant pulmonary and cardiovascular disorders, which increase the operative risk. In addition, the chronically malnourished patient tolerates operation poorly. The second factor concerns the natural history of the tumor. This highly malignant tumor invades the surrounding structures early. The first principle of adequate surgical therapy, as defined by Sweet,²⁸ is radical extirpation of the primary lesion with *en bloc* removal of a wide margin of normal regional tissue. The proximity of vital structures makes this extremely difficult. Tumors of the upper two-thirds may invade the trachea, aorta, lungs, or bronchi. Tumors of the lower third may involve the stomach, liver, or celiac axis. Since the esophagus has no serosa, there is practically no barrier to spread of the tumor. In addition, carcinoma of the esophagus has a tendency to spread along the mucosa and submucosa, setting up satellite nodules. These nodules have been noted as far as 20 cm. from the primary growth.²¹ Despite this high degree of malignancy and early spread to adjacent structures, the onset of symptoms is usually late. Dysphagia, is an almost invariable sign of advanced stages. There are no other typical symptoms. This, together with the absence of physical signs or characteristic results of laboratory tests, makes early detection almost impossible. This is one aspect of this disease in which almost no advances have been made. From 45 per cent¹² to 80 per cent⁷ of patients have evidence of metastasis at operation. Operability rates range from 22 per cent²¹ to 75.2 per cent,¹⁷ with 60 to 75 per cent of the patients undergoing exploration having resectable tumors. Of 74 of our patients who underwent exploration 64 had resectable tumors. Thus, the operability rate was 59.2 per cent and the resectability rate 43.2 per cent. In only 40 patients (32 per cent) was resection considered curative. The operative mortality rate was 25.9 per cent.

The last factor is the anatomic structure of the esophagus. This organ lends itself poorly to surgical treatment. It is thin-walled with loosely knit muscle, is fixed, has no elasticity, and retracts longitudinally when cut. The poor blood supply limits the degree of mobilization which can be accomplished. Finally, the esophagus has no protective serosa. This, coupled with

the absence of adjacent omentum to act as a seal, makes anastomosis rather difficult and tenuous at times. The strongest layer in the anastomosis is the mucosal layer. Anastomotic leaks are a major cause of operative deaths.

Numerous surgical procedures in various combinations and multiple stages^{23, 29} have been used in the treatment of esophageal carcinoma. The first successful esophagogastrectomy performed in this country was in 1937.² Most procedures consist of esophagectomy and either esophagogastrotomy or esophagocoloplasty. The results of the various methods have been essentially the same. Nakayama¹⁹ reported the highest five-year survival rate (18.4 per cent) for patients undergoing resection. Poor results have been due essentially to the fact that the primary concern has been the method of re-establishing alimentary continuity rather than more adequate control of the primary neoplasm.

Recent developments in radiotherapy, particularly supervoltage technique, has shifted emphasis to more efficient control of the primary tumor. The purposes of irradiation are to reduce the size of the tumor in the hope of facilitating resection or converting previously nonresectable lesions to resectable ones; to depress the viability of the neoplastic cells, and thereby reduce their transplantability; and to "sterilize" the regional nodes. The cervical and upper thoracic divisions of the esophagus are more superficially located and more amenable to this adjunctive therapy.

There have been some objections to roentgenotherapy, however.⁷ The first is that the time required for irradiation enables distant metastasis to occur. Second, preoperative irradiation makes the operative procedure more difficult. Finally, irradiated tissue is poorly suited for anastomosis.

Since roentgenotherapy is directed toward reducing the viability of the tumor and preventing metastasis, the short time required for preoperative irradiation seems fully justified. If operation is done too soon after roentgen therapy, the edema and acute inflammation may make the procedure technically more difficult. If it is delayed too long, the scarring and fibrosis cause technical difficulty during resection. If esophagectomy is performed three weeks to three months after irradiation, the problems are usually at a minimum. The anastomotic problem can be alleviated by limiting irradiation to the diseased segment and avoiding the esophageal segment to be used for anastomosis. The incidence of anastomotic leak or breakdown is apparently no higher in the previously nonirradiated esophagus.

The survival rate for patients with carcinoma of the esophagus treated by surgical excision alone at Ochsner Foundation Hospital is comparable to other reported series (Table 2). Of the 54 patients undergoing resection, 14 died within the first month after operation and have been considered operative deaths. During the first year after operation 20 more patients died. Therefore, only 37 per cent of patients who had esophagectomy were alive at the end of one year. At the end of five years only 5 patients were alive. Thus, the five-year survival rate was 4 per cent for the entire series but 12.5 per cent for those "undergoing curative resection." One patient, when last

Table 2. *Reported Five-Year Survival Rates for Esophageal Tumors*

AUTHOR	NO. OF CASES	PER CENT
Nakayama ¹⁹	286	18.4
Logan ¹⁴	544	14.9
Ochsner Clinic	125	12.5
Mustard et al. ¹⁷	381	10.6
Ellis et al. ¹⁰	909	9.0
Parker et al. ²¹	166	9.0
Kay ¹²	119	8.7
McManus et al. ¹³	138	8.0

examined one year after resection, and another three years after, had no evidence of recurrent disease. They were classified as one- and three-year survivals, however. Another patient died of amyotrophic lateral sclerosis six months after esophagectomy for carcinoma. At necropsy no evidence of esophageal cancer was found.

In an attempt to improve the survival rate of carcinoma of the esophagus at this institution we recently modified our method of treatment.⁵ Patients with lesions of the lower third, which have the best result from surgical treatment alone and which are poorly located for irradiation, are treated as before by esophagectomy and esophagogastrostomy. Those with lesions of the middle third are treated by preoperative irradiation, followed by esophagectomy and either esophagogastrostomy or esophagocoloplasty. Those with lesions of the upper third are treated by substernal colon transplants, followed by irradiation and esophagectomy.

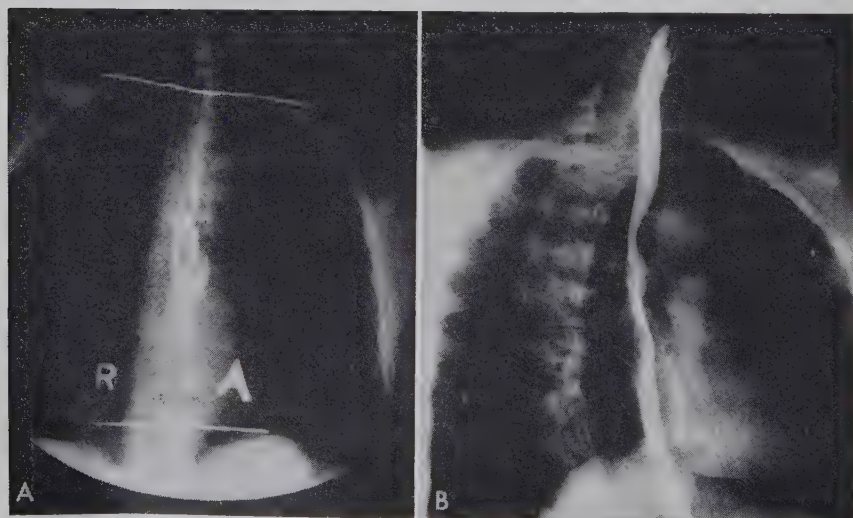


Figure 2. Roentgenograms show large tumor of the middle third of the esophagus (A) before irradiation and (B) after irradiation.

Insufficient time has elapsed since this program was begun to permit evaluation of its effectiveness. Initial experience has been promising, however. Figure 2 shows the roentgenograms before and after irradiation of a patient with squamous cell carcinoma of the middle third of the esophagus. There is considerable improvement in the postoperative roentgenographic appearance of the esophagus. At operation the esophagus appeared normal and it was extremely difficult to determine where the tumor had been. No difficulty was encountered during dissection. The mucosa of the esophagus appeared normal but on histologic examination there were microscopic nests of neoplastic cells in the wall of the esophagus. There was no evidence of spread to regional nodes. Symptomatic improvement experienced by these patients after irradiation may make it difficult to convince them of the necessity for excision. Resection is imperative, however.

OTHER MALIGNANT TUMORS

These are extremely rare. Other types of malignant esophageal tumors are leiomyosarcomas and fibrosarcomas predominantly, but cases of carcinosarcoma²⁰ and pseudosarcoma⁸ have been reported. Only one case of leiomyosarcoma of the esophagus has been seen at Ochsner Foundation Hospital. This patient had esophagoscopy biopsy, which showed squamous cell carcinoma. Roentgenotherapy had been ineffective. At exploration a nonresectable leiomyosarcoma of the esophagus was found. The patient died on the twelfth postoperative day. In a recent review 33 cases of leiomyosarcoma were collected. Our case would be the thirty-fourth to be reported. In general, leiomyosarcomas grow slowly and can be either polypoid or infiltrating. They are equally distributed at various levels of the esophagus. They are encountered most frequently in men in the sixth decade of life. Treatment is surgical excision, these tumors being radioresistant. Unless distant metastases are present, the prognosis is slightly better than with squamous cell carcinoma.

SUMMARY

From January, 1942, to January, 1964, 137 primary neoplasms of the esophagus were seen at the Ochsner Clinic and Ochsner Foundation Hospital. Results of treatment of benign tumors were good but the survival rate of patients with esophageal malignant tumors was poor. For this reason, we recently modified our method of treatment. Treatment for lesions of the lower third is esophagectomy and esophagogastrectomy; for tumors of the middle third it is preoperative irradiation, followed by esophagectomy and either esophagogastrostomy or esophagocoloplasty; and for tumors of the upper third it is substernal colon transplant followed by irradiation and esophagectomy. Insufficient time has elapsed since initiating this program

to enable adequate evaluation of its effectiveness. The initial results, however, have been promising.

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Treatment of Pulmonary Metastatic Disease

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Pulmonary metastatic disease was formerly thought to be evidence of hopeless progression of malignant disease, but resection of the metastatic lesion, in carefully selected cases, has changed this hopeless prognosis for many patients. Divis⁶ performed the first successful resection of pulmonary metastasis in 1926 in Germany. Four years later, Torek¹⁴ was the first in the United States to successfully resect a pulmonary metastatic lesion, which, however, was considered preoperatively to be a primary tumor. Barney and Churchill² were the first in the United States to remove what was considered to be a metastatic pulmonary lesion. The patient, a 55-year-old woman, had a mass in the left pulmonary field. Nephrectomy was performed on April 18, 1932, for adenocarcinoma of the kidney. Despite roentgenotherapy, the pulmonary tumor continued to enlarge. On July 18, 1933, wedge resection of the left upper pulmonary lobe was performed, and the tumor proved to be metastatic. The patient died of coronary disease 23 years later.¹⁶

Thomford and associates¹³ reported the largest series on record of patients with pulmonary metastasis treated surgically (221 operations on 205 patients). Richardson¹¹ collected 35 cases of pulmonary metastasis in children treated by excision.

White and Krivit¹⁵ reported 2 cases of lengthy survival after resection of pulmonary metastasis. One was a 21-month-old baby with a Wilms's tumor treated by nephrectomy and irradiation. One year later two nodules developed in the left upper lobe of the lung, which were removed by wedge resection; the patient was well ten years later. The second was a 6-year-old child with a rhabdomyosarcoma in the right side of the neck, which was incompletely excised and treated with 3000 roentgens. Nine months later a

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nodule developed in the lingula and was removed by wedge resection; the child was well five years later.

Wilkins and associates¹⁶ reported a series of 67 patients who had had 75 operations for removal of pulmonary metastasis. One patient had three separate thoracotomies, 4 had bilateral operations, and, in 2, second procedures were done on the same side.

In 1963, results in 25 cases of metastatic pulmonary lesions in which 28 operations were done at Ochsner Foundation Hospital were reported.¹⁰ Since then 6 additional patients have been operated on.

Diagnosis

Usually the diagnosis is made by routine roentgenography of the chest. Symptoms have been reported in a small percentage of patients. A chronic cough is the most frequent; hemoptysis, thoracic pain, and fever have also been mentioned. In rare cases hypertrophic pulmonary osteoarthropathy^{1, 7, 13} has been reported. Cytologic and bronchoscopic examinations are not as helpful in diagnosis as in primary tumors of the lung.

Surgical Indications

Removal of a metastatic pulmonary lesion is justified only if there is a possibility of cure. The patient should have no evidence of recurrent or metastatic disease other than the pulmonary lesion. The general condition of the patient should be evaluated. It is extremely important to explain to the patient and the family that the pulmonary lesion is probably not the only metastatic lesion even though no other metastatic sites can be detected. Clagett and Woolner⁴ recommended examining the patient again three months after the pulmonary metastasis is discovered. They stated that except in patients with suppuration or massive hemorrhage postponing operation for three months did not appear to be detrimental, and it provided an opportunity for other metastatic lesions, not apparent on earlier examination, to develop to a point where they could be detected. We believe that such a delay could be harmful because, in view of the number of people who smoke, the pulmonary lesion could possibly be a primary tumor rather than a metastatic one.

Personal Experience

At the Ochsner Clinic 34 operations have been performed on 31 patients with pulmonary metastasis, 3 having had two operations. Of the 34 operations, there were 16 lobectomies, 6 pneumonectomies, 5 multiple resections (lobectomy, multiple segmental resection, or lobectomy and segmental resection), 4 segmental resections or wedge resections, and 3 composite resections, consisting of removal of the thoracic wall, bony thorax, and pulmonary tissue. There were no operative or hospital deaths. Eleven patients died within the first year. One patient was known to be alive at the end of three months but could not be followed thereafter.

The distribution of cases according to duration of survival and type of primary malignant disease is shown in Table 1. Testicular tumors had the best prognosis; osseous sarcomas had the poorest. All 3 patients with sarcoma of bone died within 3 years. Patients with soft part sarcoma fared poorly also, with only one patient surviving. This patient, who had an angiosarcoma of the thigh, is living ten years after pulmonary resection. The prognosis was better in patients with carcinoma than in those with sarcoma.

Prognosis

Thomford and associates¹³ estimated the five-year survival rate after surgical treatment to be 30 per cent. This is comparable to the results of surgical treatment of many primary malignant tumors.

Although our series is small, it seems to indicate that the prognosis is influenced by the length of time that elapses before appearance of the pulmonary metastasis. Thus, the prognosis was most favorable in patients in whom the duration from primary resection to pulmonary resection was longest.

Table 1. *Duration of Survival in 31 Patients Treated by Pulmonary Resection for Metastatic Pulmonary Disease*

	NO. OF CASES	1 YR. OR LESS	1-3 YR.	3-5 YR.	>5 YR.	>10 YR.
<i>Sarcoma</i>	12					
I Soft tissue sarcoma	9					
Malignant mesenchymoma	2	1LR	1D			
Cystosarcoma phylloides	2	1D	1D			
Fibrosarcoma	2	2D				
Liposarcoma	1			1D		
Rhabdomyosarcoma	1	1D				
Angiosarcoma	1					1L
II Osseous sarcoma	3					
Osteogenic sarcoma	2	1D	1D			
Fibrosarcoma	1		1D			
<i>Carcinoma</i>	19					
Adenocarcinoma, colon and rectum	5	1L 1D 1LR	1D			1L
Adenocarcinoma, breast	4	1D		1D 1LR	1L	
Undifferentiated carcinoma, stomach	1		1D			
Malignant melanoma	5	1L 1LR 2D		1D	1L	
Seminoma	1					
Embryonal adenocarcinoma, testes	1				1L	
Squamous-cell carcinoma, cervix	1	1D				
Squamous-cell carcinoma, tonsil	1		1L			

D=dead. L=living. R=recurrence.

Collins⁵ was convinced that the prognosis is greatly altered by the interval before pulmonary metastasis becomes evident. He collected 180 cases of pulmonary metastases which were suitable for study of the rate of growth in the pulmonary neoplasm. The average time for the tumor to double in size was 116 days. The average duration of the pulmonary metastasis when first seen was 127 months, with a range from 64 to 225 months. Wilkins and associates¹⁶ reported only a 10 per cent five-year survival rate in patients who had had pulmonary resection less than five years before resection of the primary tumor. The patients who had had pulmonary resection more than five years after resection of the primary tumor had a five-year survival rate of 40 per cent. Thomford and associates¹³ reported a three-year survival rate of 22.6 per cent in those in whom the interval between resection and appearance of the metastatic lesion was less than one year, 42.6 per cent for an interval of one to four years, and 40.62 per cent when the interval was more than four years.

The longest survival on record is 23 years¹⁶ in a patient with renal adenocarcinoma. Jensik and Van Hazel⁸ reported extremely poor results with treatment of malignant renal lesions.

Kelly and Langston⁹ reported better results in sarcomas than in carcinomas. This is contrary to our experience as well as that of others.^{12, 13} Streider¹² reported a 41 per cent survival rate for carcinoma and only 33 per cent for sarcoma. Thomford and associates¹³ reported a 32.5 per cent five-year survival for carcinoma as compared to a 23.1 per cent five-year survival for sarcoma. In the series of Wilkins and co-workers,¹⁶ the best prognosis was in urinary lesions (13 per cent five-year survival), followed by uterine (12 per cent), endocrine (10 per cent), mammary (6 per cent), and gastrointestinal (4 per cent). Of 17 patients with melanoma and 27 with miscellaneous lesions, none survived five years. On the other hand, Chang and Niguidula³ believed that there is no correlation between the length of survival and the type of tumor.

Conclusion

Resection of metastatic disease of the lung in selected cases results in little risk and the expected survival rate of 27 to 30 per cent represents total salvage. Resection should be performed only in patients in whom no other evidence of metastasis can be detected and there is a possibility of cure. The longer the interval between resection of the primary tumor and appearance of the pulmonary metastasis, the better the prognosis. The prognosis is also better in patients with carcinoma than in those with sarcoma.

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Pneumoperitoneum After Pulmonary Resection

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In performance of resection of pulmonary tissue, the surgeon's major concerns are eradication of the existing pathologic process and, in procedures of lesser magnitude than pneumonectomy, preservation of function of the remaining pulmonary tissue. Whereas many infectious ailments which required pulmonary resection are happily less prevalent today, the incidence of resection for neoplastic disease continues to increase. A high percentage of patients with malignant disease of the lungs are in the older age group. In such patients, selection of an operative procedure with a chance for cure or palliation, and compatible with preservation of adequate pulmonary function, is of utmost importance. Total pneumonectomy is often necessary and is admittedly preferable, because it is more in keeping with the principles of radical excision for cancer. Nevertheless, the long-term results of treatment by less extensive resection in properly selected patients compare favorably and are attended by a lower mortality rate and less disability as a result of diminished pulmonary function.⁹ Furthermore, many patients in whom diminished pulmonary function contraindicates pneumonectomy can withstand less extensive pulmonary resection if function of the remaining pulmonary tissue can be preserved. In such patients all known practical therapeutic measures to insure rapid, uncomplicated, postoperative convalescence with optimum pulmonary function should be employed.

In wedge excision and segmental resection, the actual volume of pulmonary tissue removed is not great and consequently the dead space resulting from its removal is usually minimal. Dead space which causes difficulty usually results from lobectomy, lobectomy and segmentectomy, or bilobectomy. In such instances, prompt adaptation of the involved hemithorax to the remaining pulmonary tissue in that hemithorax must be effected. Prompt coaptation of the expanded pulmonary tissue with the boundary of the pleural space insures obliteration of dead space and sealing of viable tissue over the region of the bronchial stump and raw parenchymal

surface which may exist. This result must be accomplished by two processes. The first is maximum expansion of the pulmonary tissue, and the second, reduction of the boundaries of the pleural space.

Equalization of Volumes of Pleural Space and Pulmonary Tissue

Maximum expansion of pulmonary tissue is accomplished by proper closure of the bronchial stump and sealing of the parenchymal air leaks insofar as practical, and use of pleural suction catheters to evacuate leaking air and insure negative intrapleural pressure. Such judicious measures to insure maximum expansion of pulmonary tissue seem to have no appreciable deleterious effect on pulmonary function.^{1, 7}

The second mechanism by which the volumes of the pleural space and pulmonary tissue are equalized is by reduction in the boundaries of this space—the mediastinum, bony chest wall, and diaphragm. The natural occurrences in this regard are mediastinal shift, splinting of the bony chest wall with narrowing of the intercostal spaces, and upward displacement of the diaphragm. The limited extent of these natural occurrences is often insufficient, and in the case of mediastinal shift, is deleterious to cardiopulmonary function. Mediastinal shift is discouraged by use of measures directed toward adjusting one of the other two boundaries.

Space-Reducing Procedures

Various types of *plombage* and *thoracoplasty* may be performed on the chest wall. These measures may produce reduction in the hemithorax with minimal detrimental effect on pulmonary function,^{11, 12} but they entail further operative time and trauma. Moreover, their effect is permanent and complications are possible.

The mobile, yielding diaphragm represents the remaining boundary of the thorax, and several space-reducing measures are available to take advantage of these qualities.^{3, 6, 10, 13}

Phreniclasia results in space reduction for a prolonged period and phrenic evulsion, permanently. The deleterious effect on the function of both lungs and great impairment of ability to cough have resulted in virtual abandonment of these procedures. *Transplantation of the periphery of the diaphragm* to a higher position on the chest wall has been advocated as a space-reducing maneuver.³ Its effect is probably comparable to diaphragmatic paralysis, and it has not gained widespread popularity.

Pneumoperitoneum affords a most effective and innocuous means of using the extreme mobility of the diaphragm as a space-reducing procedure. It can be employed with a high degree of efficacy and minimum dysfunction. Although long used in the treatment of tuberculosis, its use as an adjunct of pulmonary resection is of relatively recent origin. Bickford and co-workers² mentioned its use in conjunction with diaphragmatic paralysis. Buechner and associates⁵ observed beneficial effects in patients undergoing pulmonary resection for tuberculosis who had pneumoperitoneum as part of preopera-

tive collapse therapy. They fortuitously noted, in the postoperative roentgenograms, a tendency toward greater accumulation of air beneath the diaphragm of the operated side and considerable reduction in volume of the corresponding hemithorax. Patients who had pneumoperitoneum had a lower incidence of postoperative complications than those who did not have pneumoperitoneum. Use of pneumoperitoneum in our patients in whom need for a space-producing procedure was anticipated has been so gratifying that we use it exclusively now.⁴

Changing Indications for Lobectomy

Indications for lobectomy have changed considerably during the past ten to fifteen years. The incidence of tuberculosis, bronchiectasis, pulmonary abscess, and other inflammatory respiratory ailments has steadily declined and that of neoplastic disease gradually increased. Both metastatic and primary pulmonary tumors can often be treated by lobectomy with a good chance of cure or prolonged palliation if complications can be prevented in the operative and postoperative period. These patients often have marginal pulmonary function, and justification for attempting surgical treatment is predicated on postoperative convalescence uncomplicated by bronchial fistula, persistent air leaks, persistent dead space, empyema, or pneumonia. I am convinced that pneumoperitoneum definitely helps to decrease the incidence of such complications. When properly employed, the procedure is innocuous and virtually free from adverse effects.

Dangers of Pneumoperitoneum

One avoidable fatality in our series must be acknowledged. This tragedy has not served as a deterrent to use of pneumoperitoneum, but rather has emphasized the necessity for its proper use. Attempted transdiaphragmatic institution of pneumoperitoneum by needle puncture resulted in fatal embolism. This complication has been emphasized,^{5, 8} and points out the necessity for adherence to sound, well-established principles. Insertion of a small catheter into the peritoneal cavity under direct vision through a small opening in the dome of the diaphragm is the only requirement for safe use of this valuable procedure. In only one instance was it necessary to abandon the procedure because the subphrenic space was found to be obliterated.

Technical Aspects

In none of our patients was pneumoperitoneum instituted before operation or continued after discharge from the hospital. The volume of air instilled should be determined by the size and habitus of the patient, but in most patients 2,500 cc. is a satisfactory amount. There is rarely any necessity for reduction in the pneumoperitoneum because of compression of pulmonary tissue. In 17 of our 60 patients, from one to three refills of 1,000 cc. to 2,500 cc. of air have been used during the postoperative period. This

has been dictated by the persistence of dead space or leakage of air as evidence of incomplete fusion of the pleural spaces. More air can be safely added to an existing pneumoperitoneum by use of the conventional abdominal route with the patient in the supine position.

The rate of absorption of air from the peritoneal cavity varies considerably in the individual patient. In some, the air disappears within a few days, whereas in others it may remain for several weeks. Serial roentgenograms of the chest provide objective evidence of the status and efficiency of the pneumoperitoneum. Pneumoperitoneum does not cause pain. The possibility of air embolism seems to be the only danger. The efficiency of pneumoperitoneum seems unrelated to which lobes are removed. The greater the likelihood of development of difficulty due to dead space in patients who are to undergo lobectomy, lobectomy and segmentectomy, or bilobectomy, the stronger are the indications for an adjunctive measure to reduce the dead space.

Extensive thoracoplasty would be necessary to obtain the degree of reduction of volume of the hemithorax that is easily and atraumatically obtained by safe employment of pneumoperitoneum.

PERSONAL EXPERIENCE

Pneumoperitoneum has been employed in 60 patients after lobectomy or resection of greater portions of the lung. The indications for resection are listed in Table 1, and the distribution of cases according to type of resection is shown in Table 2. The patients ranged in age from 12 to 75 years; 19 of 30 patients with bronchogenic carcinoma were between 60 and 75 years of age. There were 3 hospital deaths among the 60 patients; the death, already mentioned, due to air embolism from improper institution of pneumoperi-

Table 1. *Indications for Pulmonary Resection in 60 Patients on Whom Pneumoperitoneum Was Performed*

INDICATION	CASES
Primary carcinoma	30
Bronchiectasis	6
Tuberculosis	5
Metastatic tumors	4
Unresolved pneumonia	4
Cryptococcosis	3
Broncholithiasis	2
Pulmonary abscess	2
Pulmonary granuloma	2
Carcinoid bronchial adenoma	1
Intrapulmonary bronchogenic cyst	1
TOTAL	60

Table 2. *Type of Resection in 60 Cases of Pneumoperitoneum After Pulmonary Resection*

TYPE OF RESECTION	CASES
Left upper lobe	24
Right upper lobe	14
Right lower lobe	8
Left lower lobe and lingula	4
Right middle and right lower lobes	4
Left lower lobe	3
Right upper and right middle lobes	2
Right middle lobe	1
TOTAL	60

toneum and 2 others due to extensive bronchopneumonia. One death occurred in a 60-year-old woman with advanced drug-resistant tuberculosis, and the other, a 75-year-old man with bronchogenic carcinoma. Postoperative complications occurred in 8 patients. In 4 patients atelectasis developed in the remaining portion of the lung in the hemithorax from which the resection had been performed. In 3 patients atelectasis was in the remaining segments of the left upper lobe after left lower lobectomy and lingulectomy and in the other it was in the right middle and lower lobes after right upper lobectomy. In all 4, the process was corrected by evacuation of the inspissated material in the bronchus. In one patient, the air space persisted but disappeared after reinstitution of suction catheter. In another, bronchial fistula developed after the left upper lobectomy closed on prolonged tube drainage. In a third patient, postoperative empyema subsided after institution of drainage. In a fourth patient, postoperative accumulation of pleural fluid responded favorably to reintubation.

The following cases are illustrative of the beneficial effect of pneumoperitoneum as an adjunct to pulmonary resection:

CASE I. A 60-year-old man had a lesion of the left upper lobe of the lung discovered on routine roentgenography of the chest (Fig. 1). No abnormality had been demonstrable in a roentgenogram of the chest made six months earlier. The patient had noted no change in his health which could be attributed to this lesion. He had had a chronic cough, which he thought was due to excessive smoking for 45 years.

On physical examination, no abnormalities pertaining to the pulmonary lesion were detected. Results of skin tests, bacteriologic and cytologic examination of the sputum, bronchoscopy, and scalene node biopsy failed to establish a diagnosis. Treatment consisted of left upper lobectomy and instillation of 2,000 cc. of air into the peritoneal cavity. The lesion proved to be bronchogenic carcinoma with no evidence of spread to twelve peribronchial lymph nodes included in the excised specimen. The increased anteroposterior diameter of the original roentgenogram of the chest suggested the desirability of a space-reducing procedure. Postoperative roentgenograms demonstrated the efficacy of the pneumoperitoneum in helping to

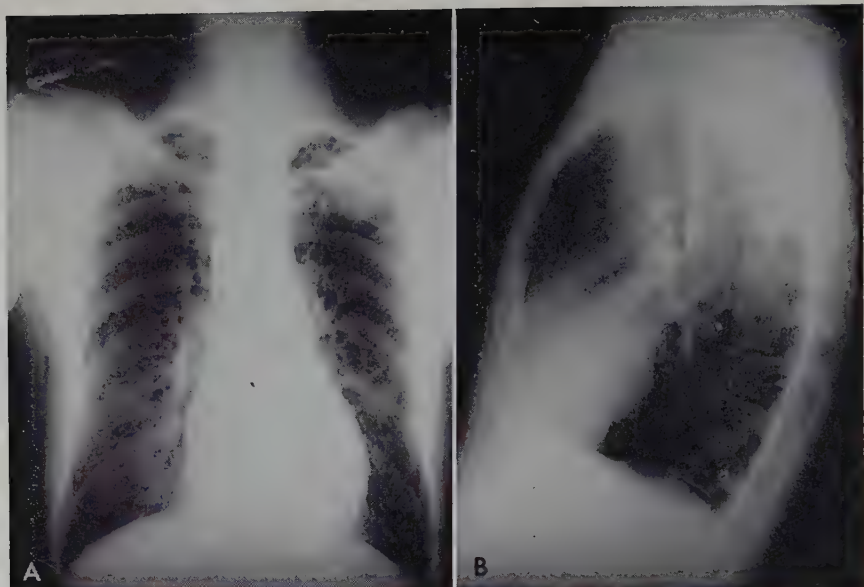


Figure 1 (Case I). Anteroposterior and lateral roentgenograms of the chest demonstrate the lesion in the apical posterior segment of the left upper lobe.

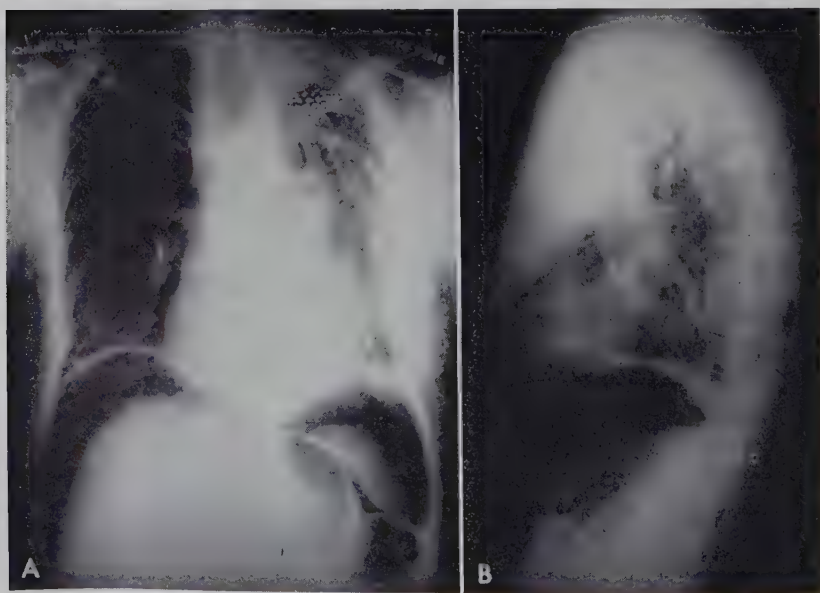


Figure 2 (Case I). Anteroposterior and lateral roentgenograms of the chest immediately after operation show the efficacy of pneumoperitoneum as an adjunct in adjusting the volume of the left hemithorax to the volume of the remaining lobe. Note that the mediastinum is not shifted.

insure obliteration of the dead space (Fig. 2). The patient obtained excellent palliation (Fig. 3).

CASE II. A 38-year-old white man complained of weakness, malaise, night sweats, and a nonproductive cough of four weeks' duration. He showed no evidence of deterioration of his usual state of good health.

On roentgenography of the chest, suggestion of an old inflammatory process of the right lower pulmonary lobe was demonstrated (Fig. 4). No previous roentgenograms of the chest were available for comparison. Severe stenosis of the right lower lobe bronchus was visualized at bronchoscopy and by bronchography. Examination of the sputum and bronchial biopsy failed to indicate the cause of the stenosis. Results of skin tests for tuberculosis, blastomycosis, and coccidiomycosis were negative but positive for histoplasmosis. Results of serologic studies for syphilis, including *Treponema Pallidum* Immobilization, were negative. Brisk bleeding from the biopsy site occurred at the time of bronchoscopy. Five days later about 1,000 cc. of blood was coughed up and necessitated emergency thoracotomy to control bleeding. The right middle and lower lobes of the lung were resected because of extremely dense tumefaction in the region of the intermediate bronchus and distally. Pneumoperitoneum (2,500 cc.) was instituted (Fig. 5). The histologic report indicated a cicatrizing process involving the bronchus of the lower lobe. Histologic study revealed healing granulomas, extensive fibrosis, and focal chronic inflammation. Neither tumor nor specific organisms were demonstrable. The presumptive diagnosis was histoplasmosis. The postoperative course was satisfactory and the patient has remained well (Fig. 6).

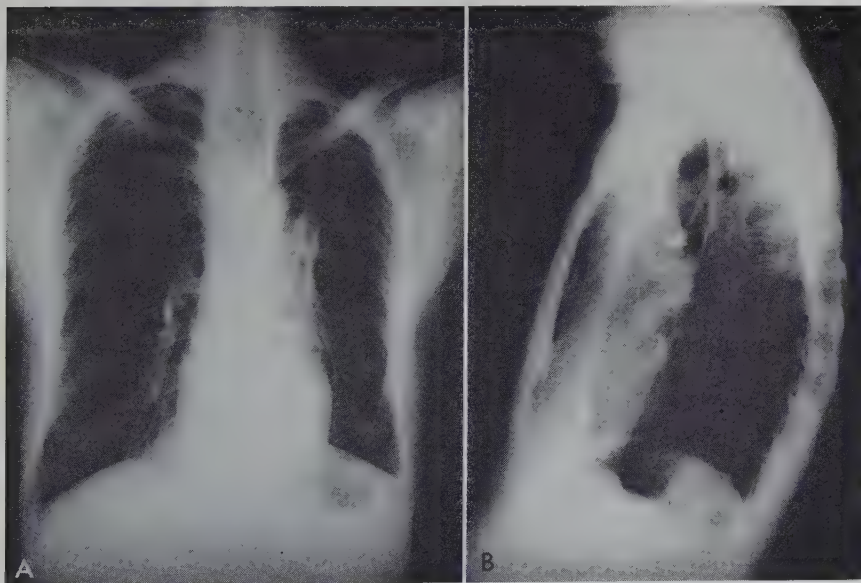


Figure 3 (Case I). Late postoperative anteroposterior and lateral roentgenograms of the chest indicate good healing and preservation of function of the lobe remaining in the left side of the chest.

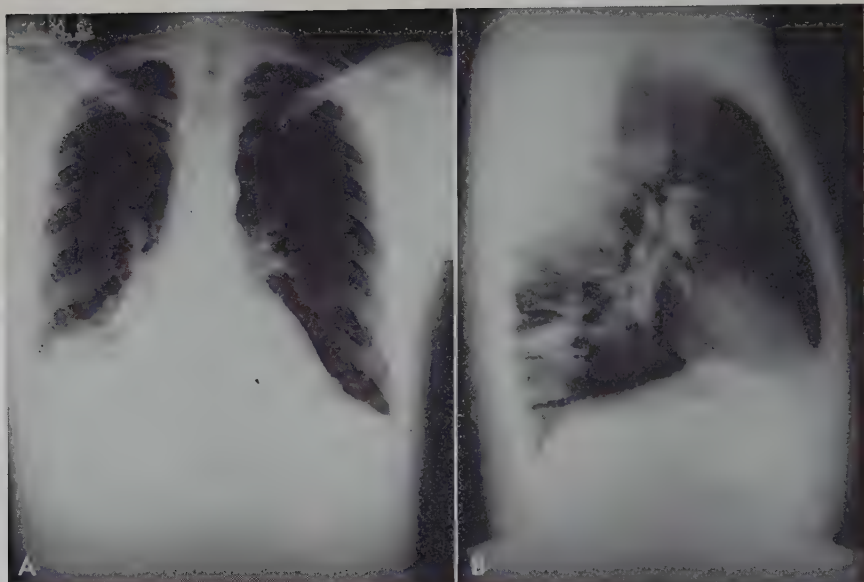


Figure 4 (Case II). Anterior and lateral views of the chest demonstrate disease in the right lower lobe, suggestive of an inflammatory ailment.

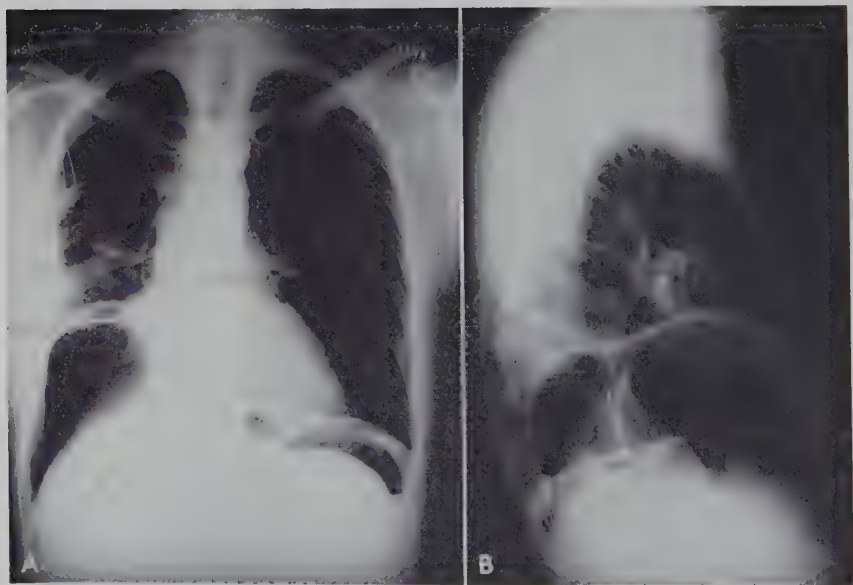


Figure 5 (Case II). Early postoperative anteroposterior and lateral views of the chest demonstrate the rather selective elevation of the right diaphragm after resection of the right middle and lower lobes for an inflammatory process presumed to be histoplasmosis.

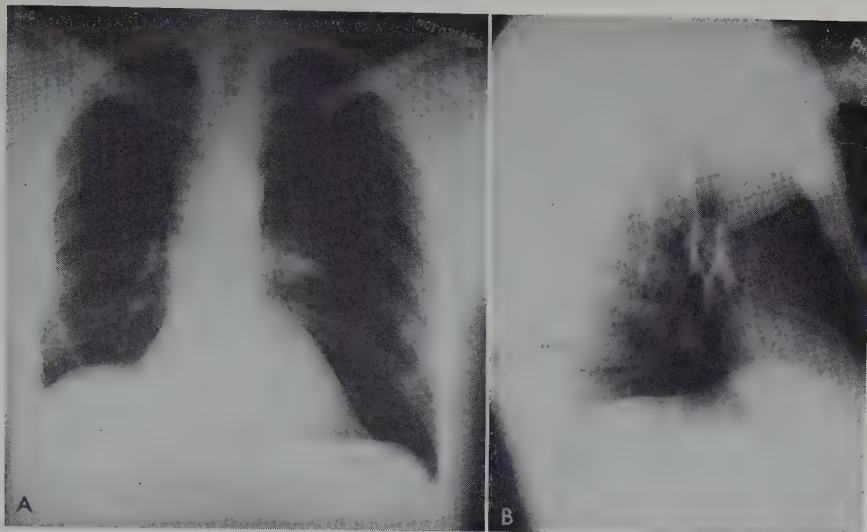


Figure 6 (Case II). Late postoperative anteroposterior and lateral roentgenograms of the chest demonstrate good healing and accommodation of the right upper lobe in the right hemithorax, without necessity for mediastinal shift.

SUMMARY

Pneumoperitoneum, instituted at the time of lobectomy, lobectomy and segmentectomy, or bilobectomy, has proved to be a highly effective adjunct to pulmonary resection of this magnitude. Its safe employment by a technique described is a rapid, atraumatic, effective, and temporary method of adjusting the volume of the hemithorax to the volume of the remaining pulmonary tissue. There is an ever-increasing number of patients with carcinoma of the lung in whom pulmonary resection offers the best chance for cure or palliation. Impaired pulmonary function because of associated emphysema and the natural results of advancing age renders many of these patients unfit for pneumonectomy. Most of them could tolerate less extensive resection if technically possible and if the risk of postoperative complications are kept to a minimum. Experience with 60 patients on whom pneumoperitoneum has been performed indicates that it is a most valuable adjunct in this regard.

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Bronchiectasis

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The importance of bronchiectasis as a challenge to the surgeon has decreased steadily during the last 25 years. This trend should continue. For more than a century, from the earliest descriptions of dilated bronchi until sulfonamides became available in 1940, bronchiectasis ranked almost equally with tuberculosis as the most serious chronic pulmonary disease.

The technique of pulmonary resection was perfected, largely because of the necessity for removing lobes and lungs destroyed by bronchiectatic changes. Resection was the most effective treatment available in serious cases before World War II. The remarkable advances in many fields of medicine^{5, 6, 8} have reduced the need for surgical intervention.

PATHOGENESIS

Collapse of one or more of the anatomic divisions of the lung is accepted generally as the primary cause of bronchiectasis. Any change that will prevent movement of air into a portion of the lung results in collapse. This state may come about gradually or suddenly, as is noted in some patients after operation.

Tumors, foreign bodies, broncholiths, and postinflammatory stenosis can all produce collapse distal to the obstruction. Dilatation of the obstructed bronchus follows and this, if sustained, is bronchiectasis. Lander and Davidson,¹¹ using gum acacia to obstruct the bronchi of cats, noted dilated bronchi in every instance. Extrinsic pressure, primarily from enlarged lymph nodes, and also from tumors, dilated blood vessels, and other structural abnormalities, produce similar changes.

Destruction of bronchial walls by infection, with weakening and dilatation, as a primary cause of bronchiectasis is now less of a problem, with tuberculosis still the major etiologic agent. Secondary infection almost

inevitably enhances the effect of obstruction, unless the latter is removed promptly.

Collapsed lung has much less volume than expanded lung. It consists of smooth muscle and elastic fibers and fibrous tissue. This area exerts traction in all directions, including the walls of the bronchi, and the intrapleural pressure is high. The degree of dilatation that develops depends on the thickness of the bronchial wall. This gives rise to one of the common descriptive classifications of bronchiectasis (cylindrical in thick-walled bronchi, saccular in intermediate bronchi, and cystic dilatation in terminal bronchi). Relief of obstruction, even after infection is at work, can result in complete re-expansion, resolution of inflammatory changes in the bronchial wall, and essentially normal bronchial systems.

In contradistinction to the localized type of change previously described, patients with inadequately treated or unrecognized chronic bronchitis, asthma, and the mucoid impaction syndrome may have widely scattered bronchiectatic areas. Mucoviscidosis, described by Andersen,² might be considered a unique cause of patchy bronchiectasis.

CONGENITAL BRONCHIECTASIS. Conclusive proof of the congenital origin of bronchiectasis seems lacking. The syndrome described by Kartagener,¹⁰ and later by Adams and Churchill,¹ has been accepted widely as the best example. The syndrome consists of sinusitis, situs inversus viscera, and bronchiectasis, usually of the transposed right lower lobe.

"REVERSIBLE BRONCHIECTASIS." Ochsner¹² and later DiRienzo⁷ used bronchography to demonstrate the presence of sharply localized spasm at the bronchial junctions, as though a string were tied about the bronchus. Distal to this spasm, the bronchi may be considerably dilated and may show definite cylindrical or saccular changes. Administration of epinephrine will rapidly change the caliber of the bronchi. Bronchi of normal caliber will be demonstrated in the bronchogram made after administration of epinephrine.

We have encountered a number of these patients, mainly adolescents, with histories of sudden onset of cough, high temperature, wheezing, and little expectoration. The regular use of bronchodilator drugs will often prevent such attacks.

LOCATION. In almost all reported series, the commonest site of bronchiectasis is the left lower lobe. The left main bronchus has a smaller diameter than the right and crosses the mediastinum at an angle. Possibly these factors are responsible for predilection of the disease for the left lower lobe. In well established left lower lobe bronchiectasis, the lingular division of the upper lobe is also involved in up to 80 per cent of cases.¹⁴

The right middle lobe is diseased almost as often statistically. Based on observation in recent years, one is tempted to consider it the most commonly involved lobe. The long bronchus and the number of lymph nodes surrounding it make the middle lobe a prime target. Up to 50 per cent of patients with right middle lobe disease are reported to have involvement of

one or more of the following: inferior segment of the right upper lobe and anterior basilar segments of the right lower lobe.

INCIDENCE

Bronchiectasis is a disease of the young. Perry and King¹³ found 69 per cent of their patients to be younger than 20 years of age. Borrie and Lichter³ recorded onset of symptoms in 66 per cent of patients before the age of ten years.

The true incidence of bronchiectasis is unknown. Whatever the figure may be, the frequency and severity of the disease are decreasing steadily in all parts of the world, in an irregular pattern. Ochsner, DeBakey, and DeCamp¹³ reported 96 resections during a 16-year period ending in May, 1948; most of these operations were done at this institution. In the ensuing 16 years, only 49 resections for bronchiectasis were performed here.

Effective vaccines are rapidly eliminating the infectious diseases in children which often resulted in bronchiectasis. Tuberculous adenitis, a major previous cause, is being controlled by widespread use of tuberculin skin testing, chemotherapy, and BCG vaccine.

Antibiotics, effective against almost all bacteria, are available. Roentgenography of the chest is being performed more often in both symptomatic and asymptomatic persons. There is increasing awareness of the importance of adequate bronchial drainage as part of the treatment in all respiratory illnesses. Foreign bodies are removed earlier. Bronchoscopy and tracheostomy are used frequently in good postoperative management of patients.

Bronchiectasis will remain a medical problem in the foreseeable future. Development of new cases may be attributed as much to the physician as to the patient if the techniques outlined are not used widely.

CLINICAL MANIFESTATIONS

Cough is one of the classic symptoms in bronchiectasis, except in disease of the apical and posterior segments of the upper lobes, which are well drained by gravity. The frequency and severity of coughs are affected by the liquidity of the sputum, by proper drainage, and by such complicating factors as smoking, asthma, sinusitis, and chronic bronchitis. Cough is necessary to empty dilated and inelastic bronchi.

Purulent sputum, varying in amount and rapidity of formation, is also a constant finding in bronchiectasis, except in the apical and posterior segments of the upper lobes. If medical treatment is intensive, the amount may be considerably reduced and at times may be eliminated. Today one rarely

encounters the patient who raises several hundred cubic centimeters of foul-smelling sputum daily.

Hemoptysis, ranging from streaked sputum to brisk hemorrhage, is reported frequently. Borrie and Lichter³ reported bleeding in 20 per cent of patients. On rare occasions, bleeding may be so profuse as to require prompt surgical control. Fatal hemorrhage is even rarer. The only symptom of "dry bronchiectasis" in the apical and posterior segments of the upper lobes, and occasionally elsewhere in the lungs, may be hemoptysis after strenuous exertion.

Localized wheezing may be a source of annoyance to the patient. Generalized wheezing due to smoking or asthma may mask this symptom. Dyspnea may be expected if the patient has extensive destruction of the lung, or associated pulmonary or cardiac disease. Systemic symptoms (recurrent fever, anemia, fatigue, anorexia) depend on the amount of suppuration present.

The physical signs will vary tremendously, depending on the extent and duration of structural damage and the severity of infection. Persistence of coarse, or moderately coarse, post-tussive rales for a long time is the most constant physical finding. Although these rales are not always indicative of bronchiectasis, in a patient subject to recurrent respiratory infection, they are a prime reason for bronchographic evaluation.

DIAGNOSIS

An informative history, with or without abnormal physical findings, and vice versa, may suggest the diagnosis. Routine roentgenograms will indicate reduction in volume of pulmonary tissue. The diagnosis of bronchiectasis, however, is always established by adequate bronchographic demonstration of the disease.

The often quoted statement of Churchill and Belsey⁶ that bronchiectasis has usually reached its full extent at the time the diagnosis is made, is still valid. The changes already present may become more severe, however. This statement emphasizes the importance of mapping the bronchial system completely before the diagnosis can be certain, or excluded. Such study is imperative before surgical treatment is considered.

Bronchograms that clearly show adequate filling of all branches of the bronchial tree require painstaking technique on the part of the operator and the radiologist, regardless of the method used to instill the contrast material. New developments in radiologic equipment and use of water-base contrast material have given consistently better bronchograms in recent years.

Adequate preparation of the patient is of equal importance. Profuse bronchial secretions with or without wheezing indicate that a good study is not feasible. Adequate treatment for as long as is necessary to clear the airways must be carried out.

Fear is a normal reaction of patients to any procedure that may interfere with breathing. A frightened patient is an uncooperative patient. Careful explanation of the procedure and answering all the patient's questions will usually allay the patient's fears. Adequate preoperative sedation, after questioning in regard to drug sensitivity, makes the procedure easier for everyone.

SURGICAL TREATMENT

Selection of Cases

Patients with bronchiectasis, even of considerable extent and severity, can be treated successfully for many years by medical measures. These include conscientious use of means to insure adequate bronchial drainage; plentiful fluid intake; postural drainage; use of expectorant and bronchodilator drugs; judicious use of proper antibiotics for adequate periods of time if the sputum is purulent; elimination of external irritants, such as smoking, atopic allergens, and dusts; and instruction in the most effective methods of breathing and coughing.

If medical treatment is unsuccessful, or if the patient is uncooperative, a firm basis for surgical treatment has been established. Surgical procedures will always be a necessary part of the therapeutic program available for adequate control of this disease.

All patients in whom surgical treatment is considered should have adequate evaluation of pulmonary function, both ventilatory and gas exchange factors. Results of these studies may indicate that surgical treatment is unwise. Obstructive airway disease may be demonstrated that can be alleviated by intensive preoperative treatment so that a poor surgical risk patient is converted into a reasonably good surgical risk. Techniques now available enable the physiologist to aid the surgeon in reaching a decision regarding the number of pulmonary segments that can be removed safely in a particular patient.

Bilateral resection is indicated at times. There is a possible trap involved if a decision is made to "do the worst side first." The example quoted often is the patient with involvement of the left lower and lingular division of the left upper lobe and the right middle lobe. If the middle lobe is removed as the second operation instead of the first, the patient will have the use only of a partial, overdilated, left upper lobe if anything goes wrong.

Preoperative Considerations

In determining the extent of pulmonary resection indicated in advanced bronchiectatic disease the surgeon must consider the following factors: the severity and distribution of the ectatic bronchial tissue, the amount of pulmonary function present and the amount that may be reasonably anticipated after planned pulmonary resection, and the possibility of

early or late postoperative complications and their effect on pulmonary function or pulmonary symptoms.

The surgical approach may be more conservative now than formerly because medical management can be expected to control suppuration and symptoms arising in areas of moderate bronchiectasis, and to prevent progression of such disease. This permits limitation of resection to the more severely diseased segments.

The extent of surgical excision must be decided preoperatively, as rarely are the gross observations at operation of additional help in this regard.

Operative Technique

Pneumonectomy is indicated in the rare patient with gross, usually cystic, bronchiectasis of the entire lung. Lobectomy, segmental resection, or combinations of these, are the usual operations for bronchiectasis. Bilateral resections may be performed if indicated. Careful preoperative preparation is necessary to reduce suppuration and minimize the danger of empyema. This is accomplished, as indicated, by antibiotic therapy, thinning secretions, alleviating bronchospasm, and bronchial toilet including postural drainage.

Operations may be performed with the patient in the lateral decubitus or prone position, depending on the surgeon's preference. We prefer the lateral approach. Dissection of the bronchovascular structures usually is technically easy. Dissection and division of the bronchi, arteries, and central veins to the diseased segments or lobes is accomplished first. The pleura at the margins of the diseased segments is incised. Traction may then be applied to the hilar structures and retrograde dissection of the pulmonary tissue performed, the branches of the intersegmental veins being clamped and divided as they are encountered.⁶

A clean line of cleavage is thus obtained with a minimum of hemorrhage. Hemostasis is secured, and gross air leaks are closed by ligation or gentle suturing. The bronchial stump is sutured with relatively inert material, such as Dacron or stainless steel wire. The bronchial stump is covered with pleura or soft tissues of the mediastinum.

All intercostal nerves are injected with a long-acting local anesthetic to minimize pleural and incisional pain and thus facilitate breathing and coughing. We use an ammonium sulfate-alcohol mixture (Dolamin). After partial pulmonary excision two intercostal tubes are placed for drainage of fluid and air and are connected to a large-capacity suction apparatus. The degree of suction may be varied as indicated.

We prefer to close the thorax with transcostal sutures of heavy stainless steel wire to provide a stable chest wall and to prevent traumatic intercostal neuritis. If extensive, but subtotal, pulmonary resection has been performed and difficulty in adequate expansion of the remaining lung is anticipated, a pneumoperitoneum may be employed to reduce the thoracic

capacity and facilitate early and complete filling of the thorax by the expanding residual pulmonary tissue.

Postoperative Care

Prompt, complete expansion of the remaining lung is the best means of preventing empyema, persistent bronchial fistula, or both. Prolonged leakage of air after segmental resection may prove troublesome. Patience is indicated, as sealing may occur after three or four weeks. Suction pressures should be varied from a simple water trap to a strong negative suction of 30 to 40 cm. of water.

The thoracic tubes are not removed until at least 24 hours after cessation of all air or fluid discharge through the tubes. If drainage has completely ceased, the tubes may be removed even though there is a moderate residual pneumothorax after the remaining lung has become adherent to the chest wall. Under these circumstances development of empyema is possible but not inevitable. If empyema occurs, the space must be drained and then closed either by simple parietal pleurolysis or by partial thoracoplasty.

Adequate bronchial toilet is the other principal postoperative goal. After pneumonectomy this is a minor problem, as the remaining pulmonary tissue has not been traumatized. After lobectomy, and particularly after segmental resection, considerable bronchorrhoea and bronchial bleeding may be anticipated from trauma to the remaining ipsilateral pulmonary tissue. Repeated vigorous coughing must be encouraged and is facilitated if the intercostal nerves have been anesthetized. Repeated nasotracheal catheterization is indicated. If this proves inadequate, bronchoscopy may be necessary. Appropriate antibiotic therapy is continued until pulmonary expansion has occurred and the bronchorrhoea and fever have subsided.

Formerly, bronchiectasis sometimes developed in previously healthy pulmonary segments which, after excision of other portions, assumed a dependent position in the chest. With careful medical supervision, including prompt control of pulmonary infections, however, this unfortunate late complication should now occur rarely. If a significant portion of pulmonary tissue has been destroyed by the infectious process, or has been surgically removed, cigarette smoking is strongly contraindicated both to minimize bronchitis and to prevent further loss of pulmonary function through bronchospastic disease or obstructive emphysema.

CONCLUSION

Improved medical therapy of acute and chronic bronchitis has lowered the incidence of bronchiectasis. More effective medical treatment has also reduced the morbidity from established bronchiectasis so that the need for surgical treatment has been significantly reduced. In the presence of

symptomatic, relatively discrete bronchiectasis that is difficult to control medically, however, surgical extirpation of the diseased segments may be beneficial.

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Funnel Chest (Chonechondrosternon)

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Although the term *pectus excavatum* is probably used more often than funnel chest to designate this deformity, it is not accurately descriptive. *Pectus excavatum* in Latin means hollowing out of the breast. Since this condition is not a depression of the breast but a funnel-like depression of the body and xiphoid of the sternum and adjacent cartilages, the terms funnel chest or chonechondrosternon, as suggested in 1938,¹⁷ are correctly descriptive.

Funnel chest is a relatively common deformity in which the sternum and adjacent cartilage are displaced dorsally to form a concavity from cephalad to caudad and from side to side. The depression usually begins at the manubrium-gladiolus junction and becomes progressively deeper toward the xiphoid process. The maximum region of depression varies in degree of asymmetry and severity. With asymmetry the sternum is rotated on its long axis so that its anterior surface is rotated toward the hemithorax of lesser anteroposterior diameter. In most cases, the heart is displaced to the left with right axis rotation.

Funnel chest is said to be congenital and often familial, although some doubt the validity of either concept. Its cause remains obscure, but many theories have been proposed. The two most popular range in complexity from a simple, ligamentous attachment between the xiphoid process and the diaphragm, to a complex abnormality in location, rate, length, and direction of costocartilaginous growth. Respiratory obstruction during neonatal life and respiratory effort, secondary to infection during infancy, have been considered supplementary factors in the production of funnel chest. Despite many studies, the true cause and course of this anomaly are poorly understood. Although the deformity usually exists at birth, it has been stated that it does not develop until after the age of 2 years in more than one-third of patients.¹⁶ This has not been our experience. We believe that the anomaly is present in some form at birth, whether it is scarcely detectable or produces a severe cosmetic deformity. Funnel chest is unusual in that it may remain

unchanged, become worse, or improve with growth of the child. There is no way to predict its course. Often the severity of sternal depression is not apparent in an obese newborn infant but becomes progressively noticeable as the body develops.

CLINICAL MATERIAL

Between 1944 and 1965, 170 patients with funnel chest were seen at the Ochsner Clinic. Although methods have been suggested to standardize the degree of severity of the deformity, our cases were classified into mild, moderate, or severe. Such a classification is relative, since the patients were seen by many different physicians and the classification was subject to the individual physician's visual sense of cosmetic perception. In the records where the deformity was described, the patients were equally distributed among the three groups.

Operative correction was not recommended in 132 patients. The remaining 38 patients, all of whom had severe funnel chest, had some form of surgical correction. The ages of those operated on ranged from 1 to 45 years, more than 50 per cent of whom were between 2 and 8 years of age.

PATHOPHYSIOLOGY

Published reports on funnel chest are confusing because much of the information is contradictory. Abnormal pathophysiologic alterations^{8, 13, 23} as well as no physiologic disturbance^{20, 27} have been described. To add to the confusion, such conflicting reports are supported by clinical and laboratory data. Those who attribute symptoms to funnel chest believe they are due to the severity of the deformity. Frequent infections of the upper respiratory tract, dyspnea, failure to thrive, and an asthenic growth pattern are the most common manifestations of funnel chest.

This thoracic malformation has been reported to cause cardiac disturbances,^{15, 28} even cardiac failure or sudden death.²⁸ Others^{5, 6, 27} believed that symptoms are never the result of cardiac disturbance, and that if cardiac malfunction exists, it is the result of a concomitant cardiac anomaly and is in no way related to the thoracic deformity. Cardiac auscultatory abnormalities are often associated with funnel chest. Such abnormalities were found in 57 per cent of 137 cases of funnel chest.²⁵ A systolic murmur was heard in nearly two-thirds of those with abnormal auscultation, and splitting of the second heart sound or a third heart sound was recorded in the remainder. The systolic murmur is best heard along the left sternal border and is of the ejection type. The cause of this murmur is unknown, but it has been attributed to compression of the great vessels, impact of the heart on the sternal bulge, and compression of the outflow tract of the right

ventricle. More than likely, it is the result of a combination of all these factors.

Electrocardiographic changes, also common in patients with funnel chest, are due to rotation and displacement of the heart toward the left, as well as the unusual position of the electrodes as the result of the abnormal chest wall.^{4, 14} Abnormalities include right axis deviation, persistence of the juvenile pattern with T-wave inversion across the right precordial leads, and incomplete right bundle branch block. Improvement or correction of the electrocardiographic pattern after correction of the deformity has been reported. Cardiac catheterization yields normal systolic pressures in the venae cavae and right heart chambers. Frequently reported is a post-systolic dip with an elevated end-diastolic pressure in the right ventricle, plus a slight pressure gradient across the pulmonary valve. Compression of the right ventricle between the spine and a greatly depressed sternum, as seen in patients with severe funnel chest, in our opinion is a valid explanation for the elevation of an end-diastolic pressure in the right ventricle. This mildly elevated pressure appears, however, to have no clinical significance.

Angiocardiography has demonstrated compression of the right ventricle, in which the imprint is situated between the inflow and outflow tracts, or more frequently, on the outflow tract and infundibulum.⁷ The amount of compression of the anterior wall of the right ventricle does not seem directly related to the severity of the funnel chest deformity, but appears to be inversely proportional to the amount of lateralization of the heart. Data from both cardiac catheterization and angiography support the hypothesis of limited expansion of the right ventricle by the thoracic malformation. This hypothesis is strengthened by the fact that, in constrictive pericarditis, identical cardiac catheterization data may be obtained on the right ventricle, that is, a ventricular curve characterized by a diastolic dip and plateau effect. The plateau is at the high level of the pressure at the end of diastole. In patients with funnel chest, right ventricular diastolic pressure is normal or slightly elevated and never greater than one-fourth of the systolic pressure.²⁷ This indicates minimal or slightly moderate compression, which is attended by no evidence of constrictive cardiac function. Cardiac catheterization was performed in 7 of our patients classified as having severe deformities and yielded data consistent with normal hemodynamics.

Extensive pulmonary function studies in patients with funnel chest have given widely varied results. Usually function is unaltered, and when abnormalities are detected they are incompatible with significant pulmonary disability.^{18, 22} They are due to restriction of movement rather than obstruction.^{18, 23} Rarely, a malformation is so severe as to impair pulmonary function.²⁰ Impaired cough mechanism and hypoventilation as a result of the deformity and a fixed chest wall have been reported.² Decreased pulmonary function, demonstrated preoperatively, has remained unchanged after surgical correction of the funnel chest. In fact, decrease in cardio-

pulmonary function after operation has been reported.¹⁹ Although many reports refute the possibility of abnormal pulmonary function, it is logical to expect a deformed chest wall (characterized by a depressed, fixed sternum associated with some degree of scoliosis) to cause decrease in respiratory exchange.

INDICATIONS FOR OPERATION

Opinion also differs widely regarding indications for surgical correction of funnel chest. Some²⁷ believe that operation is of no benefit. Others¹⁸ think that operation can help the occasional patient with an obvious physiologic disturbance. That all patients with the malformation should be treated surgically even though they have no complaints or demonstrable cardiac or pulmonary disturbances, as suggested by some,¹² is unrealistic, for the operative risk and the frequently poor surgical result certainly outweigh any questionable prophylactic benefit in patients in whom the necessity for correction is questionable. Somewhere between the two extremes lies the proper approach. Only a few deformities are so severe as to cause physiologic alterations; in such patients surgical correction is indicated. In most patients, assurance that the condition is benign is all that is necessary. Some patients have a severe cosmetic deformity which apparently causes no physiologic disturbance but does cause the patient some concern. Two courses are possible, and time usually helps the physician, patient, and parents make the decision for or against operation. Since it is impossible to predict the significance of a funnel chest at birth, the patient should be observed at intervals to determine whether the malformation worsens, remains unchanged, or improves. Frequently, the adolescent patient or the parents of a child request surgical correction on the basis of the cosmetic and psychologic effect of the deformity on the patient. It is imperative that the physician inform the responsible party of the true nature of the condition and operative results. Predictions of future physiologic disturbances, which are uncertain, should not be injected to support the decision. Often, there is no relation between the patient's complaint and the severity of the deformity.

We have seen a few children whose malformations were so severe that they failed to thrive. Whether underdevelopment is due to cardiac impairment, pulmonary impairment, or both, is unknown, but some of these children begin to grow immediately after surgical correction, and continue to do so.

The ideal age for correction remains controversial. Certain ages have been designated as best for surgical correction based on experience. Some¹⁶ advocated repair before the child is 2 years old. Others^{24, 30} reported better results when operation was performed between 2 and 6 years of age, and some⁸ preferred to operate during adolescence. Thus, the age at which opera-

tion is performed appears to be a personal preference, which is probably based on the fact that certain surgical techniques are ideally applicable at a particular age.

TREATMENT

The numerous operation^{1, 3, 9, 10, 11, 15, 19, 22, 29} devised for correction of funnel chest attest to the fact that no method is ideal for all ages and anatomic variations. In general, the operation used by us was the one in vogue at the time, unless the anatomic deformity lent itself better to a different technique. In most operations a rib strut was used to position forward and stabilize the sternum, probably because at the time this technical maneuver was considered to give the best results with the least morbidity.

At present we prefer Ravitch's²¹ method if the deformity is corrected during infancy or early childhood. He uses subperiosteal excision of the cartilage along the full length of the deformity, separation of the sternum from the manubrium, a transverse osteotomy at the junction of the manubrium and gladiolus, and no external fixation. In older children and adults we combine this technique with forward stabilization of the sternum by passing a Kirschner wire transversely through the body of the sternum, allowing the wire to rest on the rib cage bilaterally in the subcutaneous position. The rod is removed three or four months later, after complete fixation of the sternum.

As mentioned, several operative techniques were used in our series (Table 1). A few maneuvers were common to most procedures, which include excision or mobilization of all the involved costal cartilages, removal of the xiphoid process, and osteotomy with fracture of the sternum at the junction of the manubrium and body of the sternum. Often it was necessary to fracture the body of the sternum transversely or longitudinally in order to mold it into a suitable form. In two-thirds of the operations, a rib strut was used to elevate and immobilize the sternum. External traction to a Parham-

Table 1. *Distribution of 38 Patients with Funnel Chest According to Type of Operation*

OPERATION	NUMBER OF PATIENTS
External traction	2
Rib strut and external traction	3
Rib strut	21
Kirschner wire strut	4
No strut or traction	7
Sternotomy	1
TOTAL	38

Martin band attached to a bivalved upper body case was used to elevate the mobilized sternum or to supplement a rib structure in the earlier cases. In one man in the fifth decade of life with extensive calcification of the costal cartilages, the sternum was completely excised, reversed, and returned to the thorax where it was resutured for immobilization. Recently, a Kirschner wire has been used to stabilize and elevate the sternum in 4 patients.

Results

Results were designated as good, fair, or unimproved according to cosmetic appearance (Table 2). Most patients obtained good results. In 6 patients, whose initial result appeared good, the deformity recurred, to a lesser degree in 4 and to the same degree in 2. Others¹⁶ have reported recurrence of the deformity, which has no relation to the severity or initial operative result of the original condition. Recurrence often is not apparent for two years or more and does not become severe for many years. Therefore, the operative results cannot be properly assessed for at least five years after correction. Two of our patients with unfavorable results fractured the rib strut by a fall during the early postoperative period, and undoubtedly this accident contributed to their poor results.

There were no operative deaths in our series. Many complications occurred, some of which are common and somewhat expected. Pneumothorax occurred in 10 patients (30 per cent). Unless the pneumothorax represents at least 30 per cent of the involved hemithorax, treatment is unnecessary. If, however, it appears greater than 30 per cent of the hemithorax or as a combined amount bilaterally, simple thoracocentesis is employed to remove the air.

Three patients had chronic draining sinuses, one of which necessitated a second operation. All of these sinuses subsequently closed with sequestration of foreign bodies. Pericarditis developed in 2 patients and responded satisfactorily to supportive care. One patient had cardiac arrest in the Recovery Room secondary to cardiac tamponade from mediastinal (internal mammary artery) bleeding. This patient was resuscitated in the Recovery Room but had to be returned to the operating theater for control of bleeding and repeated repair of the correction after closed chest cardiac massage. The patient has remained well with excellent correction of the deformity.

Table 2. *Results of Operations in 38 Patients with Funnel Chest*

RESULTS	NUMBER OF PATIENTS
Good	32
Fair	4
Unimproved	2
TOTAL	38

SUMMARY

Funnel chest (chonechondrosternon) is a relatively common congenital condition of varying severity. As the infant develops, it improves, remains unchanged, or worsens, and there is no known means of predicting its course. Because pathophysiologic alterations associated with this condition are uncertain, there is much disagreement concerning the physiologic disturbances caused by a funnel chest deformity.

One hundred and seventy patients with funnel chest were seen at the Ochsner Clinic during the past 20 years. Because of the apparent benignity of the condition, operative correction was not recommended in 132 patients. In 38 patients some form of surgical correction was performed. Surgical correction is usually performed for cosmetic or psychologic reasons, since most patients are asymptomatic. Results of operation are usually good, although recurrences have been reported.

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Foreign Bodies in the Tracheobronchial Tree and Esophagus

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The exact incidence of foreign body accidents will probably never be known, as many cases go unrecognized. Haugen³ reported that 9 deaths initially attributed to heart attacks were found to be due to obstruction of the airway caused by unchewed food. Many people probably die from unrecognized foreign bodies each year. The National Safety Council lists ingestion of foreign bodies as the leading cause of accidental deaths in the home in children younger than 6 years of age.

These accidents are often avoidable if certain precautions are observed. Carelessness in preparation of food may result in the ingestion of bones, seeds, glass, metal, eggshell fragments, wood splinters, and even pins and buttons from the cook's clothing. Eating seafood entails a high risk of ingestion of small bones and fragments of crab, lobster, or oyster shells. Careless, hasty eating and drinking, with improper mastication and failure to detect a bone either visually or by tactile sensation in the mouth contributes to the cause. Permitting children to play while eating, permitting those younger than 4 years old who have unerupted molars to eat nuts and watermelon, and leaving small objects within reach of infants are invitations to accidental ingestion of foreign bodies. Failure to close safety pins and the habit of chewing a stem of grass while watching athletic events or other forms of entertainment are additional contributors. Laughter, anger, spirited discussion, excitement, sobbing, crying, whistling, singing, hiccough, falling, and a blow on the back have all caused accidental ingestion of foreign bodies.⁶

The incidence of foreign bodies of dental origin has increased during the past 30 years.⁴ This increase may be due to greater use of dentures, which can themselves become foreign bodies, or it may be attributed to the fact that teeth serve as an insulator to the tactile oral mucosa so that the person is less able to detect foreign bodies in food. In the edentulous person who does not wear dentures, impaction of unmasticated foods, such as meat, fruit and vegetable pulp, is relatively common.

Failure of the dentist to isolate the operative field from the rest of the

oral cavity increases the risk of ingestion or aspiration of filling material, tooth fragments, broken bits of dental instruments, and prosthetic material. The increased speed of the dentist's maneuvers, crowding of the mouth, and hyperactive reflexes on the part of the patient all tend to increase the likelihood of aspiration of foreign bodies.

Attempts to retrieve a loosened tooth or other object from the back of the mouth by using a finger have often caused the object to be aspirated into the tracheobronchial tree. Varying degrees of topical and local anesthesia have resulted in loss of the atomizer tip or even the suction tip into the pharynx. The anesthesiologist, the tonsil surgeon, and even the bronchoscopist have inadvertently caused dislodgement of a deciduous or permanent tooth with subsequent aspiration into the tracheobronchial tree. If such an accident is discovered at the time it happens, the foreign body, of course, should be removed if possible. Holinger and associates⁴ advised that, if the foreign body cannot be removed at the time of the accident, the patient or his relatives should be advised of the accident and what must be done about it. The patient should then be hospitalized, if he is not already in the hospital, for complete preoperative investigation. Should thoracotomy or gastrotomy become necessary, good doctor-patient relationship will help minimize the psychic trauma. Finally, immediate consultation with an endoscopist should be arranged so the foreign body can be promptly removed.

FACTORS WHICH HINDER EARLY DETECTION OF FOREIGN BODIES

Failure of Parents to Seek Medical Attention. The rapid fatigue of the cough reflex after aspiration, usually within ten to fifteen minutes, followed by an asymptomatic period which may last several hours to many months, tends to lull parents into a false sense of security. When secondary symptoms do appear, sufficient time may have elapsed to erase the memory of the choking episode so that this valuable clue is obscured.

The choking episode may have been witnessed only by another brother or sister, and is therefore discounted by the parents. Frequently, the innocent looking piece of candy given to the infant is not recognized as a source of peanuts until much later.

Failure of the Senile, Intoxicated, or Otherwise Mentally Incompetent to Report Foreign Body. In a recent series of ingested foreign bodies in psychotic patients, Teimourian and associates⁹ reported a mortality rate of 42 per cent in one group of 38 patients who were considered to have insufficient symptoms to warrant endoscopic or surgical procedures.

Failure of the Physician to Consider the Possibility of a Foreign Body. A foreign body in the tracheobronchial tree may present a clinical picture of acute pneumonia or laryngotracheobronchitis. In esophageal foreign bodies, the persistent vomiting that accompanies the cough or pneumonitis

may deceive the physician into diagnosing gastritis possibly of viral origin. Absence of a history of ingestion of a foreign body, of course, complicates the problem. Skepticism concerning the possibility of a foreign body, even in some patients with a strong suggestive history, may be responsible for delay in diagnosis. Occasionally, the history of a choking spell, followed by coughing up a portion of a peanut with subsidence of the coughing, will suggest that the foreign body was spontaneously expelled when actually only a small portion was expelled. The symptomless interval, which may be long in the case of a straight pin or plastic toy, or short, as in the case of vegetable materials such as a peanut or bean, may reinforce the clinical impression that no foreign body is present. Dyspnea and hoarseness are usually absent during quiet activity, even though one entire main bronchus is completely occluded. According to Kassay,⁷ a dry, spasmodic cough after fright, laughter, sneezing, or crying is a strong indication of a bronchial foreign body in a symptomless patient or one who coughs moderately. He also stressed the importance of stridor or oral wheeze, most audible during expiration when the examiner's ear is placed in front of the patient's open mouth. A special kind of stridor, called "after-blowing" because it closely follows expiration, may be the only indication of obstruction of a segmental bronchus.

ROENTGENOGRAPHIC OBSERVATIONS

Radiographic studies can be of tremendous aid to the physician, but can also be misleading. A negative result does not rule out the possibility of a radiolucent foreign body or even a radiopaque one overshadowed by the vertebral column and mediastinal structures.

A single roentgenogram of the chest taken during inspiration may show essentially normal structures even though one main stem bronchus is completely obstructed. Another film taken during expiration, however, would clearly show the asymmetrical rib cage, diaphragm, and mediastinal movements caused by the obstruction. Even when pulmonary asymmetry is noted on a single film, it is almost impossible to determine which main bronchus is obstructed. Obstructive emphysema resembles compensatory emphysema. Likewise, compression of the normally functioning lung by an emphysematous one closely resembles atelectasis produced by obstruction. For this reason, inspiration-expiration films should always be made. If further doubt remains regarding the location, fluoroscopy may be necessary to view the entire respiratory cycle. During this examination, mediastinal structures move toward the side of the lesion or obstruction during inspiration.

The asymmetrical changes produced by partial or complete obstruction of one main bronchus are relatively easy to recognize. A more subtle change is obstruction within the trachea, causing partial obstruction to both

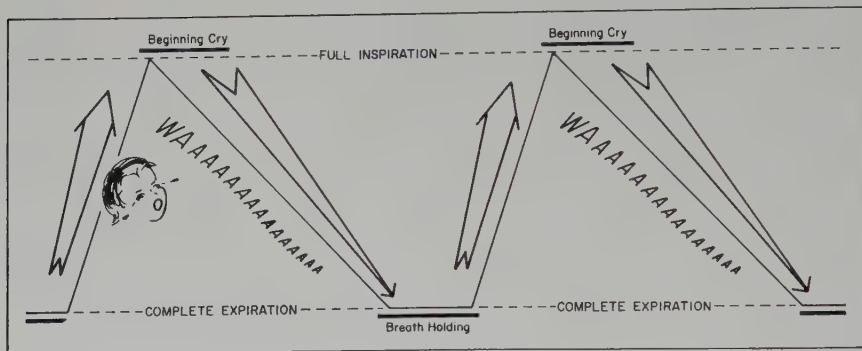


Figure 1. Diagrammatic representation of infant's crying cycle. Timing of inspiration-expiration radiographs becomes simpler when the phases of the cry can be used. The quick inspiration phase before the start of the loud cry provides an opportune moment for the inspiration film. Likewise, at the end of the cry, the lungs are in complete expiration, and a short period of apnea or breathholding provides a useful moment for taking the picture.

inspiration and expiration. The inspiration-expiration roentgenograms here may show reversal of the normal density variation of the pulmonary parenchyma. Normally, pulmonary parenchyma appears to be slightly more radiolucent on inspiration and less radiolucent on expiration. When tracheal obstruction is present, however, on inspiration, the density of the lung is increased because of more blood distending the pulmonary vessels, as well as less air in the lung. Expiration with increased intrathoracic pressure tends to empty pulmonary vessels while failing to move the trapped air from the lungs.

The value of inspiration-expiration roentgenograms is in direct proportion to their quality. Timing of the pictures in full inspiration and full expiration is relatively simple in the older, cooperative child. Similar timing in the frightened, crying, uncooperative infant may be more difficult. In the vigorously crying infant, however, the task becomes simpler. If the procedure of positioning him on the x-ray table does not cause him to cry vigorously, the dermal compression test can be administered. Figure 1 depicts the phases of the infant's cry. Taking the picture just after the end of the fading cry, during the breath-holding period of several seconds, results in an excellent expiration film. Then, a second film, made just after the breath-holding phase, when the infant has taken a deep inspiration and is just beginning to vocalize loudly again, will usually result in excellent visualization of the foreign body.

TREATMENT

Foreign Bodies in the Air Passages

The various techniques for removal of foreign bodies in the air passages have been detailed by Jackson and Jackson.⁶ No attempt will be made to

review the additional contributions of others to this broad field. Certain recent technical advances of aid to the bronchoscopist have been made in the fields of illumination and anesthetization.

Many experienced endoscopists prefer local anesthesia, or none, in the more difficult cases, relying on their skill at passing the bronchoscope and their gentle technique to avoid trauma to the delicate subglottic tissues. Others believe that general anesthesia does not increase the incidence of complications, and does facilitate gentleness while serving as a safeguard against uncontrolled laryngospasm, apnea, hypoxia, and cardiac arrest. During esophagoscopy, the thin-walled trachea may easily be compressed unless an endotracheal tube is in place during the endoscopic procedure. For this reason, I prefer general anesthesia with intratracheal intubation for removal of esophageal foreign bodies. Similarly, general anesthesia induced with halothane has proved to be a safe, reliable adjunct to the bronchoscopist. Its nonexplosive vapors can be safely administered by the sidearm of the Jackson or newer Broyles bronchoscope, along with a high concentration of oxygen. If it is necessary to ventilate the patient during the procedure, occluding the lumen of the bronchoscope with the thumb will produce rapid inflation of the lungs and sudden release will permit expiration. In addition to the feature of rapid induction, halothane has the advantage that its vapors produce less interference with light waves and less irritation to the conjunctiva of the bronchoscopist than do those of ether.

In the small infant with a foreign body in one main stem bronchus, no sedative or atropine-like premedication is given before induction of anesthesia, because further depression of the respiratory centers by use of barbiturates and thickening of the bronchial secretions is undesirable. After induction of anesthesia, intratracheal intubation is accomplished, and the level of anesthesia is closely controlled by the anesthesiologist.

With the intubated, anesthetized patient carefully positioned, the proper size bronchoscope, foreign body forceps, and suction tips are positioned within easy reach. The anesthesiologist flushes the lungs with oxygen and hyperventilates the patient for three or four deep breaths just before the tube is withdrawn. The bronchoscope is then introduced to the level of the midportion of the epiglottis, and as the endotracheal tube is withdrawn and the glottis comes into view, the bronchoscope is easily advanced through the parted cords without trauma. After the foreign body has been identified and its exact presentation determined, the appropriate forceps is introduced so that its plane of apposition will coincide with the portion of the object to be grasped. Advancement of the shaft of the forceps during closure will insure that the jaws are not retracted away from the object. Gentle pressure exerted on a peanut or other friable object will reduce the chance of its fragmenting during removal. Since most objects are too large to be brought out through the bronchoscope, the foreign body is carefully brought up to the lip of the bronchoscope and the forceps and bronchoscope

together are removed as one unit through the trachea, glottis, and oral cavity. The glottis is the critical point where, in the lightly anesthetized patient, there is great danger of losing the foreign body, owing to the "grabbing" effect of the true vocal cords.

During the procedure, depth of anesthesia is controlled by the sidearm delivery system. The pulse rate is monitored closely by the anesthesiologist. If the rate becomes ominously slow, additional oxygen is immediately administered into the sidearm, and the lungs are inflated, as previously described. In one of our patients, cardiac arrest developed after removal of one-half of a peanut from the left main bronchus. Pent-up secretions and exudate pouring out of the emphysematous lung had effectively occluded the right main bronchus. Immediate aspiration of the right main bronchus and external cardiac massage restored the heart beat within 90 seconds, with no complications. After removal of a foreign body, the bronchi should therefore be immediately reexamined. A second foreign body or collection of thick secretions may be present.

Perfection of a fiber optic lighting system for bronchoscopes has helped to eliminate one of the more troublesome components of the endoscopist's equipment. The fiber optics system requires a less vigilant maintenance program than the battery, light-cord, light-carrier, and wheat-grain light bulb systems. It is thus more dependable for use on short notice. A well maintained battery system, however, in which the multiple electrical contacts are kept free of dirt or corrosion, is equally effective.

In only one of our patients during the past six years has tracheostomy been necessary. In this infant, a triangular, convex fragment of pecan shell was wedged firmly in the subglottic tissue immediately beneath the vocal cord. As the convex surface was uppermost, pressure on its center by the bronchoscope only tended to drive its corners deeper into the walls of the subglottic area. The foreign body had to be removed through a tracheal stoma.

Foreign Bodies in the Esophagus

Esophageal foreign bodies may offer equally challenging problems of removal. Some, however, such as a coin in the cricopharyngeal region, may actually be lost during induction of anesthesia as the muscle spasm relaxes. For this reason, patients suspected of having esophageal foreign bodies are usually placed in a slight head-down or Trendelenburg position. This lessens the likelihood of the foreign body passing spontaneously into the stomach. If the endoscopist still has difficulty locating the object, he must remember to look into the nasopharynx⁶

In our experience, general anesthesia has proved far superior for removal of esophageal foreign bodies in both adults and children because of the degree of muscle relaxation as well as the uncompromised airway. The esophagram, preferably made with an optically transparent material such as iodized oil, should always be visible in the operating room. Reference to it

will lessen the chance of perforating a pharyngeal diverticulum or a malignant stricture of the esophagus which may closely simulate a foreign body.

An invaluable aid to selecting the proper instruments is having a duplicate of the foreign body for study. This may be impossible, but knowing whether or not a straight pin is made of steel or a nonmagnetic alloy might mean the difference between advising thoracotomy or not.

After removal of the esophageal foreign body the esophagus should be reexamined for possible lacerations, perforations, granulations, or strictures. Radiographs should always be made before discharge of the patient from the hospital. Search should be made for evidence of pneumothorax, mediastinitis, subcutaneous emphysema, persistent atelectasis, and resolution of inflammatory changes. In some patients, roentgenography after several weeks or months may be necessary to rule out the possibility of esophageal or bronchial stricture, or other delayed sequelae.

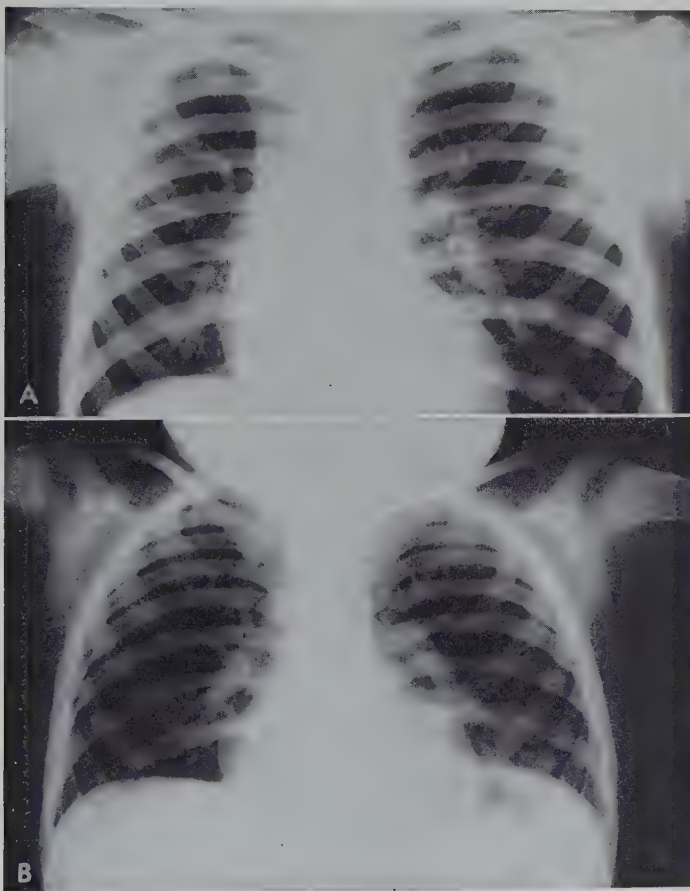


Figure 2. Occlusion of right main bronchus by pecan fragment produced mediastinal shift to the right on inspiration (A), but return to almost normal symmetry on expiration (B).

REPORT OF CASES

CASE I. A 2½-year-old white boy choked while eating a piece of pecan. On examination a definite expiratory wheeze was heard over the right middle anterior portion of the chest. Inspiratory-expiratory roentgenograms revealed a nearly normal pattern on expiration but pronounced asymmetry with shift of the mediastinum to the right on inspiration (Fig. 2). Occlusion of the right main bronchus had caused early atelectasis. The comparative position of the left diaphragm indicated that the left lung was the only one with any air exchange. After removal of the foreign body, the pulmonary dynamics returned to normal.

CASE II. A 2-year-old white girl choked while chewing a pecan on Jan. 15, 1966. Left lower lobe pneumonitis developed. Four days later, a small fragment of

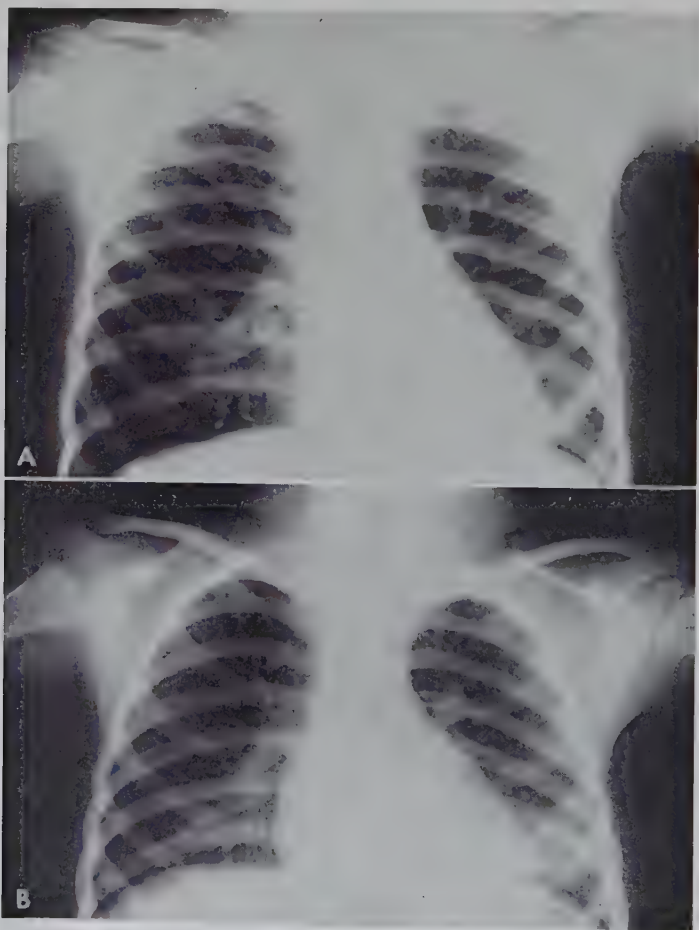


Figure 3. Partial occlusion of left lower lobe bronchus by pecan fragment produced slight shift of mediastinum to the left on inspiration (A) with normal symmetry on expiration (B).

pecan was removed at bronchoscopy. The pneumonitis recurred, and on March 4, 1966, she was first seen at the Ochsner Clinic. The inspiration-expiration roentgenograms showed slight shift of the mediastinum to the left on inspiration (Fig. 3). Bronchoscopy on March 7, 1966, revealed a residual pecan fragment blocking the left lower lobe bronchus. After its removal, the pneumonitis completely resolved.

CASE III. A 2½-year-old white boy choked while eating peanuts on March 20, 1965. After six hours, the inspiration-expiration roentgenograms indicated an air-trapping obstruction of the right main bronchus (Fig. 4). Bronchoscopic removal of friable peanut from the right main and lower lobe bronchi resulted in complete clearing of the right lung.

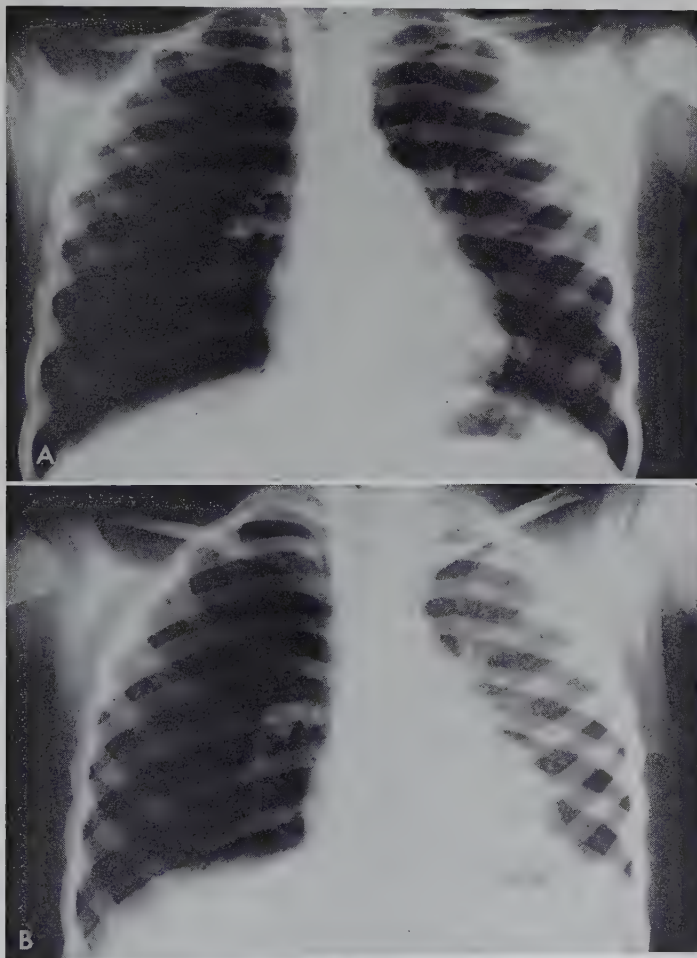


Figure 4. Partial occlusion with air-trapping obstruction of right main bronchus by half of a peanut produced emphysema of right lung. On inspiration (A), the lungs appeared nearly symmetrical. On expiration (B), however, the left lung emptied and the mediastinal structures moved to the left.

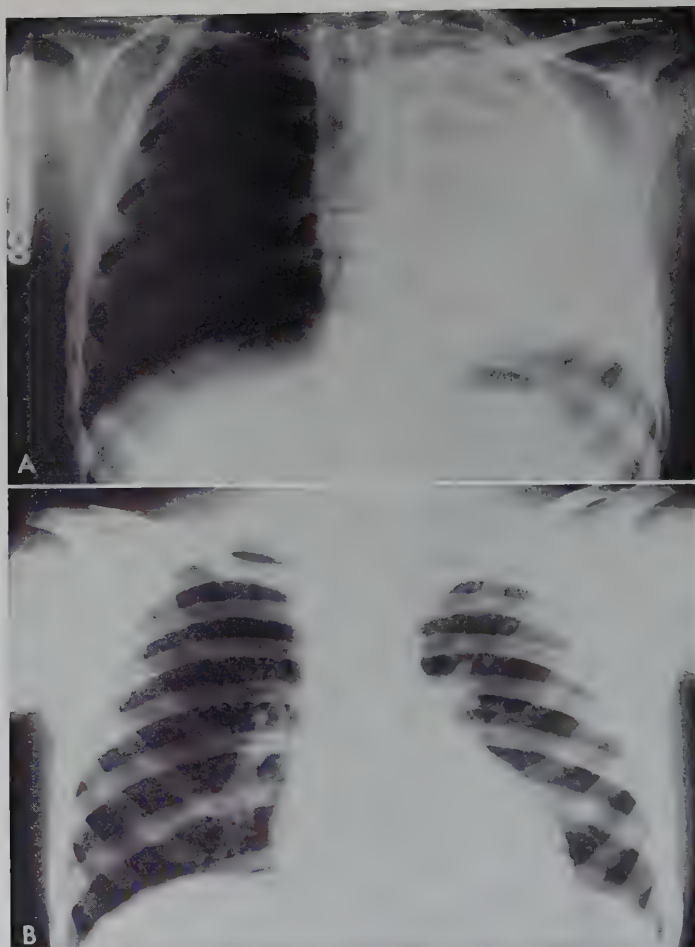


Figure 5. Partial occlusion with air-exhausting obstruction of left main bronchus by a metal screw produced almost complete atelectasis within four hours (A). Within 12 hours of removal of the foreign body, the left lung was completely re-expanded (B).

CASE IV. A 3½-year-old white boy, while playing in an automobile, aspirated a metal screw which he had found. Within four hours, the inspiration-expiration roentgenograms indicated almost complete atelectasis of the left main bronchus (Fig. 5) because of an air-exhausting type of valve action. The morning after removal of the foreign body from the left main bronchus, re-expansion was complete, and the patient was discharged (Fig. 6).

CASE V. A 1½-year-old boy choked on an unknown object while playing in early January, 1966. On January 27, 1966, he was referred to the Ochsner Clinic because of recurrent episodes of fever and cough. Attempted removal of the foreign body was partially successful, resulting in delivery of fragments of brass.

Roentgenograms revealed a metallic foreign body in the left lower lobe bronchus. Bronchoscopic removal was accomplished January 29, 1966, and the top

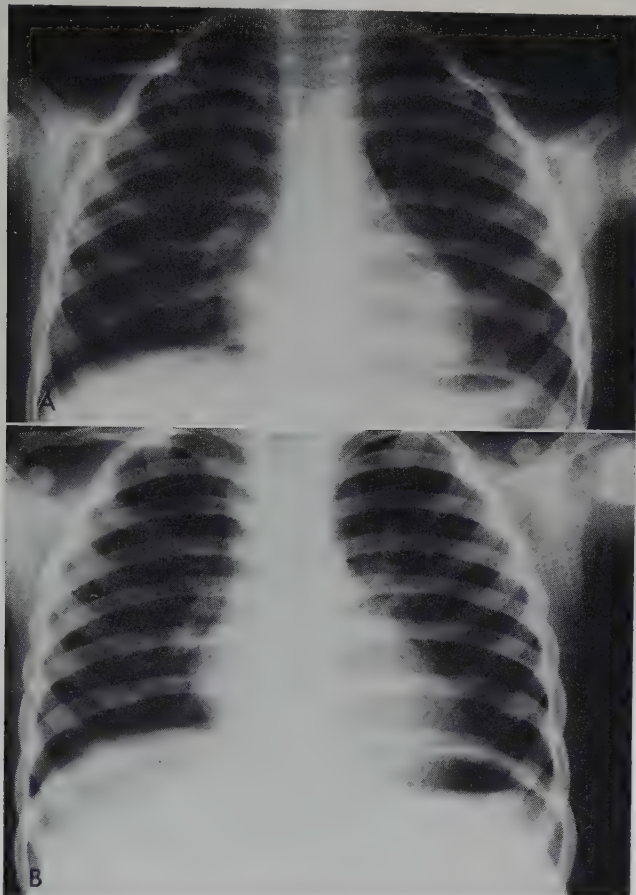


Figure 6. Incomplete obstruction by top of ball-point pen within left lower lobe bronchus produced little tissue reaction (A). Left lung appeared to be clear the morning after removal of the foreign body (B).

of a ball-point writing pen was identified. Little reaction of surrounding tissue was noted, and the left lung appeared clear the next morning (Fig. 6).

SUMMARY

Accidental introduction of foreign bodies into the tracheobronchial tree or esophagus may result from carelessness during preparation or consumption of food. Emotional preoccupation, the insulating effect of dentures, and use of local and general anesthetics further increase the incidence of these accidents.

Delays in diagnosis result from the rapid fatigue of the cough reflex, reluctance of parents to seek medical opinion, and failure of the physician to consider the possibility of a foreign body in differential diagnosis.

Roentgenographic signs of obstructive emphysema, obstructive atelectasis, and mediastinal shift are readily apparent on inspiration-expiration roentgenograms. In infants, these views are best obtained during the crying cycle.

The use of halothane for general anesthesia provides an increased safety factor for the patient and less interference with the vision of the endoscopist than ether. Fiber optic lighting system seems to be the most dependable form of illumination for removal of foreign bodies. Follow-up observation for delayed stricture or other sequelae is essential.

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Management of Thoracic Trauma

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Thoracic trauma is a common medical problem, ranging in severity from fracture of a single rib requiring no treatment to extensive disruption of the thoracic cage with concomitant injuries of multiple organs. Management of patients with the latter type of injury may tax the most diligent and conscientious physician and exhaust the laboratory and nursing facilities. Experience with treatment of military casualties has resulted in reduction in the mortality rate of thoracic wounds from 44 per cent in World War I to only 6 per cent in the Korean War.^{5, 13} This knowledge has been advantageously applied to the treatment of civilians with thoracic injuries, the incidence of which has increased in recent years because of the large number of automobile accidents which occur at high speeds. The evolution of thoracic surgery and, more recently, cardiovascular surgery as specialties has brought about a better understanding of the pathophysiology of thoracic trauma. In recent years, refinement and development of respiratory assistants, biochemical instruments capable of rapid analysis of blood gasses and cardiac output, and improved surgical procedures have all contributed to the improved care of the patient with a thoracic injury. An organized approach to correction of the various physiologic and anatomic alterations is essential in the care of victims of thoracic trauma.

GENERAL CONSIDERATIONS

The primary therapeutic objective in patients with thoracic injuries is provision of adequate oxygenation. Basic aims of treatment include provisions for effective pulmonary function and assurance of adequate cardiac action and circulatory blood volume. Critical disturbances of respiratory and cardiovascular function must be corrected immediately,

after which the injuries can be evaluated in more detail. Because these patients often have multiple injuries, careful examination of the body as a whole is necessary. Patency of the airway must be assured by whatever means is required, from simple insertion of an oral airway to temporary endotracheal intubation, bronchoscopy, or tracheostomy. Tracheostomy, which guarantees optimal ventilatory function of the lungs, is indicated in numerous conditions that cause respiratory obstruction.⁶ Besides assuring a patent airway, tracheostomy facilitates artificial respiration in patients whose respiratory center has been damaged, reduces the often detrimental dead space in certain injuries, and provides a means through which respiratory assistance can be administered to patients with severe thoracic trauma. The need for tracheostomy should be recognized and the procedure performed, rather than temporizing with more conservative measures. The unfavorable outcome of a thoracic injury should never occur because of failure to employ tracheostomy.

In addition to an obstructed airway, any condition that prevents or hampers excursion of the lungs may cause inadequate pulmonary function. These include cerebral damage; limitation of excursion because of paralysis of muscle or pain due to movement of the thoracic wall; alterations of pulmonary parenchyma by hemorrhage, edema, retained secretions, or infection; and compression of pulmonary substance by accumulation of blood, air, or displaced organs within the pleural space.

The status of the cardiovascular system must be evaluated simultaneously with that of the airway. Adequate cardiac function depends on integrity of the heart itself and availability of sufficient circulating blood volume. Clinical evidence of shock and hemorrhage serves as an index of the cardiovascular status. Roentgenography and fluoroscopy of the chest, central venous pressure measurement, electrocardiography, and analyses of blood gases are valuable adjunctive tests of cardiac evaluation.

For convenience of discussion, thoracic injuries are usually classified as penetrating or nonpenetrating. Most penetrating wounds are produced by missiles or cutting instruments, rarely by impalement. Endoscopic instrumentation or swallowed or aspirated objects rarely cause penetrating thoracic injury. The presence and pathway of penetrating thoracic injuries usually are immediately apparent, a fact which favors expeditious evaluation of the areas affected. These wounds are ordinarily of limited extent and, sparing direct injury to the heart or great vessels, the victim usually survives long enough to be treated.

On the other hand, nonpenetrating wounds are often associated with diffuse, sometimes violent, trauma, often with extensive, concealed damage to musculoskeletal and visceral structures.^{9, 14} Delay in appearance of symptoms may result in erroneous diagnosis and procrastination in treatment. Few thoracic injuries involve a single organ or structure. For convenience of discussion, they will be considered according to the site of pre-

dominant injury: (1) musculoskeletal system; (2) mediastinal structures, with the exception of the trachea and bronchi; and (3) respiratory system.

MUSCULOSKELETAL SYSTEM

Musculoskeletal injuries range from simple contusion of soft tissue or rib fracture to extensive crushing injuries. Trauma of the chest anteriorly can implicate both hemithoraces and mediastinal structures. Because of the great resiliency of the thoracic wall, children and young adults may sustain such severe trauma as cardiac or bronchial rupture without fracture, whereas such injuries in persons older than 30 years almost invariably are associated with extensive damage to bone and cartilage.^{4, 15} Simple linear fractures of the rib and sternum may cause respiratory disturbance, due to limitation of excursion because of pain. Appropriate analgesics, intercostal nerve block, and when practical, splinting, as with an encircling elastic bandage, are indicated. Extensive violence sometimes causes relatively little damage to the internal structures.

There are three types of injuries in which the primary or only defect is in the musculoskeletal system, but the major effect is registered by the respiratory or cardiovascular system: (1) a sucking wound of the chest, (2) flail chest, and (3) laceration of the diaphragm.

Sucking wounds result from penetration of the thoracic wall, often with some loss of substance. Intrapleural pressure becomes atmospheric or even greater, resulting in collapse of the ipsilateral lung and usually some compression of the opposite lung due to mediastinal displacement. Treatment consists of immediate plugging of the opening of the thoracic wall by whatever means is available, followed by decompression of the pneumothorax by intrapleural drainage placed under water as a seal.

Flail chest injuries were formerly associated principally with mining accidents and referred to as stove-in chest or crushed chest. Today the all too frequent steering wheel injury accounts for most flail chests and may or may not be associated with injury to the intrathoracic structures. If sufficient bones are fractured in at least two sites to cause a segment of the thoracic wall to float (Fig. 1), the resulting paradoxical motion greatly impairs ventilation and has a devastating effect on cardiorespiratory function. The method of treatment depends on the severity of the defect. Small areas of paradoxical motion can be controlled by simple adhesive splinting. On occasion, open reduction of fractures is justified, and a variety of traction devices, such as Kirschner wires, towel clips, or a cervical tenaculum applied about the fractured ribs, is effective in the moderately severe injury of this type.^{7, 8} Tremendous improvement in the care of the severely crushed patient has resulted from use of a mechanical respirator attached to a tracheostomy tube. This device is based on the principle of correction of paradoxical motion by having the injured wall simply ride on the regulated

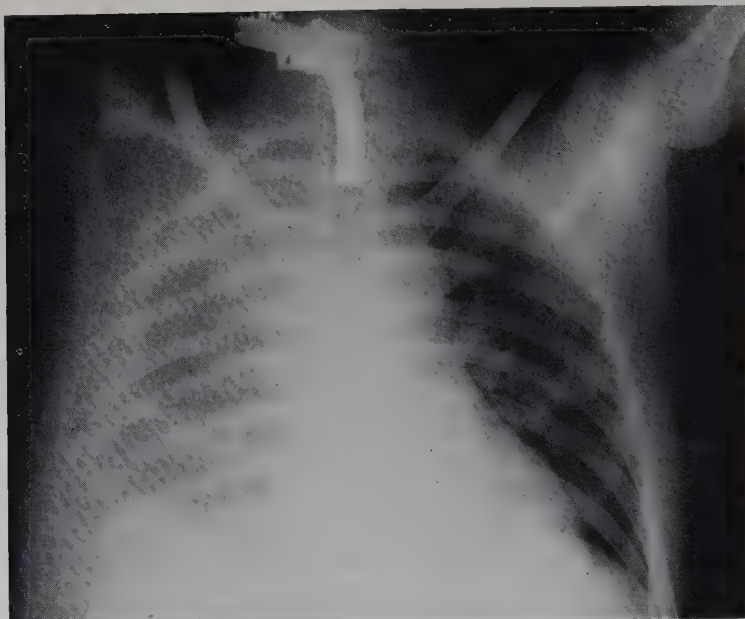


Figure 1. Anteroposterior roentgenogram of the chest reveals extensive fractures of the right hemithorax with a large segment of the chest wall floating. Tracheostomy tube for Moersch respirator is in place.

movement of the lungs.¹ The judicious use of respirators and respiratory assistants has aided in saving the lives of a great number of these desperately ill patients.

Respiratory and metabolic disturbances are usually associated with flail chest injuries. Repeated measurements of the pH, Pco_2 , and O_2 content of arterial blood are imperative to determine, correct, and maintain homeostasis. Thoracic injuries result in decrease in the oxygen content of arterial blood because of contusion of the pulmonary parenchyma and atelectasis, which result from improper expansion of the lung due to pain and instability of the thoracic cage. With the fall of O_2 content and rise of CO_2 content of the blood, respiratory acidosis ensues. Most patients with thoracic injuries lose blood with resultant hypotension and arteriolar vasoconstriction, and consequently reduced arterial perfusion of the body tissues. Contributing to the poor tissue perfusion is decreased cardiac output, associated with paradoxical motion of the mediastinum. As a result metabolic acidosis develops. In thoracic injuries immediate restoration of the blood volume and correction of metabolic acidosis are important. The early empirical use of sodium bicarbonate or tromethamine (Tham-E) is justifiable under these conditions.

Laceration of the diaphragm results from penetrating injuries or severe violence to the abdomen with increased intra-abdominal pressure. Detachment at the periphery, an unusual type of diaphragmatic injury, is asso-

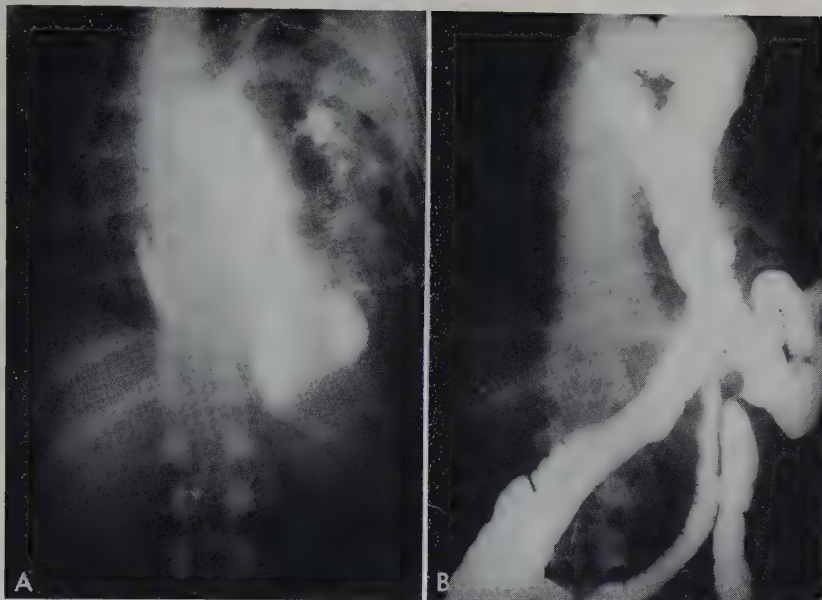


Figure 2. Roentgenograms of patient with rupture of left diaphragm. A. Displacement of stomach into left pleural space. B. Large segment of the colon also in the left pleural space.

ciated with fractures of the costal arch. Usually the dome of the left side of the diaphragm is injured, presumably because the right side is protected by the liver. Any or all mobile viscera of the upper part of the abdominal cavity thereby gain access to the pleural space, and the gas-containing nature of the abdominal viscera often causes the injury to masquerade as an abnormality of the lung or pleura. It is important to distinguish between these conditions because thoracocentesis in a patient whose gastrointestinal tract is partially within the pleural space may prove catastrophic. Roentgenographic studies of the gastrointestinal tract with barium provide confirmatory evidence of the true nature (Fig. 2). Aside from compromising pulmonary tissue and displacement of the mediastinum, the herniated organs, often through a small orifice, are subject to incarceration and strangulation. These should be repaired as soon as practical through a transthoracic approach.

MEDIASTINAL STRUCTURES OTHER THAN THE TRACHEA AND BRONCHI

As a major component of the mediastinum the heart and great vessels absorb the greatest amount of trauma to this area and may be injured directly by penetration or indirectly after blunt trauma to the chest. The incidence of *nonpenetrating injuries of the heart and great vessels* is related

to the violence of the injury. Although penetrating injuries of these organs have been recognized and treated appropriately, nonpenetrating injuries often remain obscure and are overlooked. The heart is vulnerable to an impact injury because of its closeness to the immobile vertebral column and sternum. The heart might be injured as the result of direct contact from a fracture of the sternum or ribs; compression of the heart between the sternum and vertebral column, or increased intraventricular pressure secondary to sudden compression or crushing of the abdomen or extremities. Morphologic changes of the heart from nonpenetrating trauma vary from epicardial contusion to ventricular lacerations. The seriousness of a cardiac injury, however, cannot be determined by the magnitude of force or anatomic change in the myocardium. Cardiac deaths have been reported from such minor violence as a blow to the chest from a stick and such minuscule morphologic changes as a few petechiae in the epicardium.¹² Various cardiac arrhythmias have been reported after blunt trauma to the heart, and, experimentally, ventricular fibrillation has resulted from direct blow to the heart without significant anatomic change in the myocardium.¹⁰ Unless the myocardium ruptures or fatal arrhythmia ensues, nonpenetrating injuries usually cause little morbidity. Concussion of the heart must occur with an injury sufficient to fracture the sternum. Usually, however, this type of injury is not of sufficient magnitude to be diagnosed clinically or by roentgenographic means.

Concussion and severe contusions with actual bruising of the heart are frequently demonstrated by appropriate electrocardiographic studies and elevation of the serum glutamic oxalacetic transaminase level. Comparable to myocardial infarcts, these injuries may produce a variety of disturbances in rhythm and function, and electrocardiographic evidence of myocardial anoxia and death of muscle. Cardiac arrhythmias that are not contributing to deterioration of the patient's condition are corrected by administration of appropriate anti-arrhythmic drugs. Patients with arrhythmias incompatible with sustained life are treated immediately by cardioversion with direct-current countershock, the synchronous capacitor discharge being used. Likewise, arrhythmias that are not corrected by medical management are converted to a normal sinus rhythm by electrocardioversion at convenience and when not interfering with treatment of concomitant injuries.

Treatment for cardiac contusion is supportive and similar to that for myocardial infarction. Bed rest is recommended during the period of cardiac symptoms and dangerous sequelae. Since hemopericardium and cardiac rupture rarely occur after three weeks, the duration of bed rest need not be longer than four weeks unless cardiac symptoms persist. Adequate oxygenation is imperative, and since associated pulmonary trauma is common, an adequate airway and ventilation must be assured. Analgesics will control the inevitable precordial pain. Digitalization is indicated if the myocardial injury appears significant, and every effort should be made to prevent development of congestive heart failure. Anticoagulation is contra-

indicated because of the dangers of bleeding into the injured myocardium or pericardium. Cardiac rupture is the most common cause of death secondary to nonpenetrating cardiac injuries. Exsanguination or cardiac tamponade quickly follows rupture and rarely is survival possible. With cognizance of the possible disaster and the large number of trained cardiovascular surgical teams available, however, some of these patients may be saved.

Traumatic rupture of a papillary muscle, chorda tendineae, or valve leaflet produces acute incompetency of the valve. The course after such an incident is related to the severity of valvular insufficiency. Death may occur instantaneously or the insufficiency may be negligible and produce no physiologic alterations. Immediate surgical correction is warranted if the symptoms are severe, but delayed repair is desirable if medical treatment can control symptoms without difficulty. The great vessels of the mediastinum, particularly the aorta, are subject to disruption by closed injury.¹¹ The most plausible explanation for these injuries is that they are the result of sudden deceleration accidents in which a shearing laceration occurs at the site of transition from a fixed to a more mobile segment of vessel. In the aorta these injuries are usually at the root or just distal to the origin of the left subclavian artery. Most of these patients die immediately but some survive for hours or even years with a false aneurysm. Radiographic demonstration of a widened mediastinum (Fig. 3) should alert the examiner to the possibil

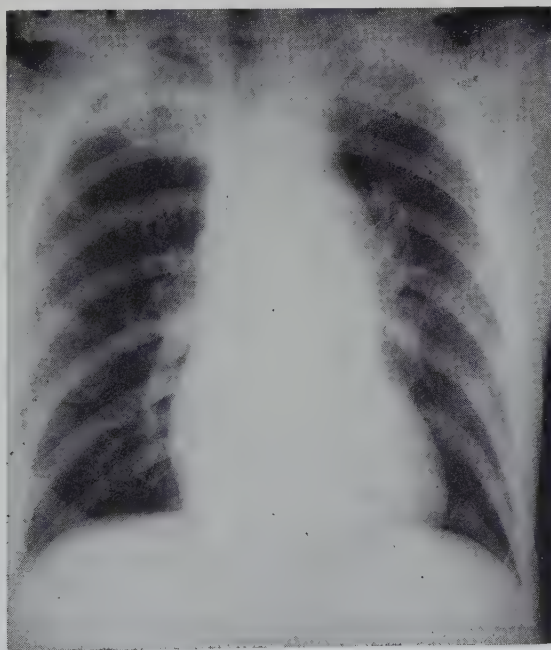


Figure 3. Anteroposterior roentgenogram of chest shows a widened superior mediastinum. Aortography proved the widening to be due to a ruptured thoracic aorta at the isthmus.

ity of a torn aorta or one of its great branches. A torn vessel must be recognized as quickly as possible; immediate surgical repair is mandatory, for fatal hemorrhage may occur at any moment. The diagnosis can usually be confirmed by venous angiocardiography. The injury is almost always just distal to the origin of the left subclavian artery, and the laceration is repaired or replaced with a prosthesis, utilizing a left atriofemoral bypass.

The more frequent *lacerations of the lesser mediastinal vessels*, such as the intercostal and internal mammary arteries, may cause hemomediastinum but usually break into the pleural space and produce manifestations of hemothorax: respiratory insult, concealed hemorrhage, diminished breath sounds, dullness to percussion, opacity in roentgenograms; and blood on thoracocentesis. Most such patients can be treated by blood transfusion and thoracocentesis; however, use of a large-bore closed thoracotomy tube assures removal of all blood and complete expansion of the lung. Rapid accumulation of hemothorax, especially with evidence of costal or sternal fractures, occasionally requires thoracotomy for control of the bleeding vessel.

Most patients with *penetrating injuries of the heart and great vessels* do not live long enough to receive treatment. Death is due to cardiac tamponade, hemorrhage, interference with myocardial conduction system, or associated injuries. Were it not for the pericardium, practically all patients with cardiac penetrating wounds would bleed to death shortly after injury. The life-saving pericardium usually prevents exsanguination but encirclement may be lethal by impediment of myocardial action in the presence of continued bleeding. Most deaths from cardiac injury are due to cardiac tamponade, which is amenable to prompt treatment. Patients with penetrating cardiac injuries may be in various physical states upon arrival for treatment, although most are obviously ill and in distress. Many without signs of distress seek treatment purely because they have been the victim of a potentially lethal weapon. The fatal nature of these wounds may prove itself at any moment; therefore, the apparently benign clinical condition of a person who has had a thoracic injury should not diminish the examiner's zest in determining the severity of such an injury, for usually prompt diagnosis and treatment are necessary for survival. The diagnosis of cardiac injury is usually that of cardiac tamponade, evidenced by lowered arterial pressure, narrowed pulse pressure, elevated venous pressure, and distant heart tones. This diagnosis is confirmed by pericardiocentesis and obtaining of nonclotting blood. Pericardiocentesis not only confirms the diagnosis but also relieves or prevents cardiac tamponade. Often this is all that is necessary in treatment of such patients. After initial pericardiocentesis the patient should be under constant surveillance, and if pericardial fluid reaccumulates, pericardiocentesis should be repeated. The necessity for a second pericardiocentesis is indication for open thoracotomy and treatment of the penetrating cardiac injury. Cardiorrhaphy should be immediately performed in the operating room.

The *esophagus* is rarely injured by penetration or perforation. This may occur from external injury, from endoscopy, or from a swallowed object. Because of the highly infectious nature of the esophageal contents, mediastinitis with or without infection of the pleural space rapidly ensues. Occurrence of signs of sepsis, even within a few hours after injury, often with pneumothorax, mediastinal emphysema, severe pain and dysphagia in one who may have perforation of the esophagus, demands immediate clarification. Obtaining highly contaminated material on thoracentesis is presumptive evidence of esophageal laceration. The most certain method of diagnosis is by roentgenography after ingestion of iodized oil with demonstration of the esophageal leak. Drainage by mediastinotomy or thoracotomy and massive antibiotic therapy should be instituted immediately, and if practical, the site of leakage should be repaired.

Penetrating or nonpenetrating trauma to the *thoracic duct* is a relatively rare complication which must be kept in mind.³ This injury is usually manifested as pleural effusion, the exact nature of which is realized when thoracentesis yields pinkish or milky fluid. The likelihood of spontaneous sealing of most lacerated lymphatic ducts dictates a period of conservative treatment by thoracentesis as necessary or closed thoracotomy drainage. Patients, however, should not be allowed to become severely depleted from prolonged loss of chyle before more active therapy, consisting of ligation of the leaking duct by thoracotomy, is undertaken.

RESPIRATORY SYSTEM

The cardinal sign of disruption of the air passages in the respiratory system is extravasation of air into adjacent tissues and body cavities. Perforation of the alimentary tract and gas-producing infections are other conditions which can produce similar findings. The clinical signs of extravasation of air into the tissues are gross swelling and crepitance, and air in abnormal sites is readily demonstrable roentgenographically.

Fracture of the larynx is an occasional associated injury, which is characterized by alteration in voice, restriction of the airway, hemoptysis, and interstitial emphysema in the adjacent fascial and subcutaneous planes. Treatment usually requires tracheostomy and sometimes restorative procedures on the larynx to obtain a satisfactory functional result.

Separation of the cervical trachea is a rare consequence of blunt trauma to the upper part of the thorax.² The trachea retracts into the upper part of the mediastinum; consequently, failure to palpate the trachea in the supra-sternal notch is diagnostic. Treatment consists of reapproximation of the trachea and tracheostomy.

Lacerations of the thoracic trachea are almost invariably due to penetrating or perforating injuries whereas major bronchial injuries are usually associated with severe closed injuries of the upper part of the thorax. Exten-

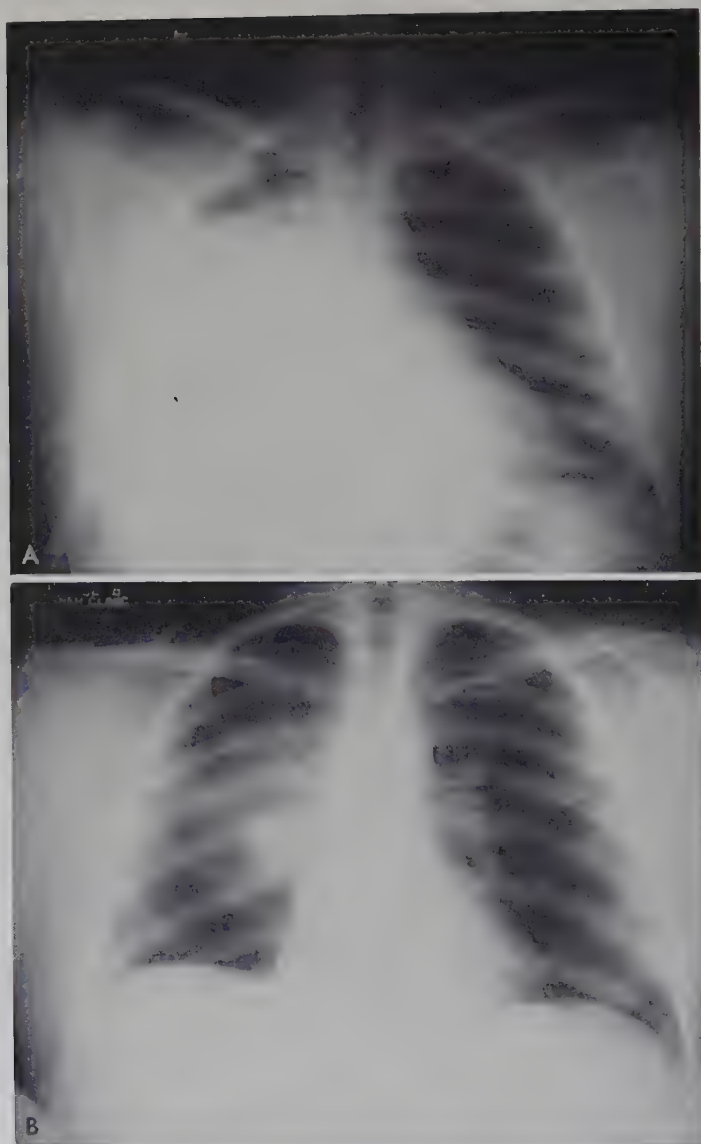


Figure 4. Roentgenograms of chest of patient with pulmonary hematoma after gunshot wound. *A*. Roentgenogram day of injury shows diffuse pulmonary parenchymal hemorrhage. *B*. Roentgenogram six weeks later shows resolution and consolidation of the hematoma. This hematoma might be considered a tumor were it not for history of injury.

sive fractures of the upper ribs usually are produced by trauma severe enough to cause bronchial lacerations in the adult. Mediastinal emphysema and unilateral or bilateral pneumothorax ensue. Severe, uncontrollable leakage of air requiring early thoracotomy for control occurs in less than half of such injuries. The remainder must be diagnosed by maintaining a high

index of suspicion. Otherwise, the diagnosis will not be made until after bronchial stenosis and atelectasis or pulmonary sepsis have developed. Accordingly, patients with severe injury of the upper portion of the thorax warrant special cognizance of the possibility of bronchial injury.

Minor leakage of air from a *pulmonary laceration associated with fractures of ribs* is extremely common. Mild to moderate extravasation of air in tissue planes is detectable, and usually is of no consequence. In such patients pneumothorax may develop in the ensuing days, and as in those in whom it appears immediately, a suction catheter should be inserted into the pleural space to re-expand the lung. Rarely, mediastinal and cervical emphysema may progress to a degree requiring decompressive cervical mediastinotomy. Tracheostomy should accompany this procedure, as it prevents development of extremes of intrapulmonary pressure, which favor progression of extravasation of air.

Injuries to the pulmonary vascular system almost invariably result in hemoptysis. Except for laceration of the larger pulmonary arteries, bleeding from these vessels is usually self-limited, owing to coagulation in the spongy parenchymal matrix or tamponade of bleeding from this relatively low pressure system. Extensive intrapulmonary bleeding—the pulmonary hematoma—may occur from closed trauma but is most often due to penetrating wounds. Solidification of the pulmonary field in association with a penetrating wound, hemoptysis, negligible returns from thoracentesis, and slight or no pneumothorax usually indicates pulmonary hematoma. These patients require antibiotic therapy because of the penetrating nature of the injury as well as the danger of infection in the hematoma. A pulmonary hematoma resolves primarily during the first few weeks but disappearance of the final residuum is often slow, and pulmonary neoplasm may be suspected if the history is not obtained (Fig. 4).

Another kind of closed, diffuse, pulmonary trauma is the "*blast injury*." It results from exposure of the lungs to sudden, extreme pressure as occurs in explosions or falls. There is usually diffuse contusion of the pulmonary tissue with extravasation of fluid and blood into the parenchyma and severe compromise of respiratory function. Treatment consists of use of all measures available to support respiratory function and may include tracheostomy, continuous administration of oxygen, and use of a mechanical respirator.

SUMMARY

Thoracic trauma is a common medical problem whose incidence has increased in recent years because of the large number of automobile accidents which occur at high speed. Thoracic injuries are usually multiple, but generally the predominant injury is to the musculoskeletal system, the mediastinal structures, or the respiratory system. An organized approach

toward the diagnosis and treatment of the various physiologic and anatomic alterations in thoracic trauma is recommended.

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Myocardial Revascularization

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Until recently, surgeons in general were unenthusiastic about myocardial revascularization. An occasional report would appear on an attempt to increase blood supply to the heart, but interest in such investigation dwindled because of lack of support by medical and surgical colleagues. Cardiologists generally did not believe that coronary artery disease should be treated surgically. Despite considerable resistance, Beck¹ and Vineberg⁷ diligently and tirelessly pursued their different courses in an attempt to reach their goal, myocardial revascularization. Throughout the years, they conducted experiments on various methods of myocardial revascularization and had the fortitude to apply to man those techniques which appeared clinically applicable. Despite repeated reports of clinical success of different surgical procedures, the medical profession was reluctant to accept them as therapeutic or practical. This reluctance was probably a healthy attitude, for leniency in scrutinization would have resulted in acceptance of many worthless and even detrimental operations. The principle upon which many of the operations were based had no physiologic parallel to other proved operations. Also, it is difficult to accept an operation on subjective evidence, particularly when claims were made of anginal relief after many operations which obviously were of no benefit. Inadequacies in methods of diagnosis and selection and evaluation of a particular surgical procedure, plus the known emotional facets of angina pectoris, added to the reluctance in acceptance of an operation in the treatment of angina pectoris. Most operations proposed for myocardial revascularization have been forgotten with time. A few, however, have continued to have some support because of improvement reported by the patients.

Pathologic and physiologic studies have been performed in an attempt to correlate the clinical picture of coronary artery disease and the pathologic alterations in the heart. Although there have been discrepancies in observations, most agree that anginal pain is the result of myocardial ischemia and

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the demand for more oxygenated blood by the heart. It has been shown that collateral circulation can revascularize an ischemic area of the heart; however, there is a limit to what the existing coronary blood vessels can accomplish. The amount of myocardial ischemia in coronary artery occlusive disease depends on the efficacy of collateral circulation and the extent and degree of coronary artery occlusion. When the myocardium does not receive adequate oxygenation, angina or catastrophic sequelae will ensue.

In 1945 Vineberg⁷ hypothesized that an extracoronary systemic artery could be implanted within the myocardium and bring oxygenated blood to an ischemic area by forming epithelial connections with intramyocardial arterioles. Experimentally, 76 per cent of such implanted arteries have remained patent where myocardial ischemia existed, and histologic examination proved the internal mammary-coronary anastomosis to be patent in 71 per cent. After extensive experimentation, clinical results were equally favorable, but few surgeons were eager to accept the operation. A great impetus to acceptance of the procedure was selective angiography, particularly selective coronary angiography, developed by Sones and Shirey.⁶ For the first time, the coronary arteries could be adequately visualized. The anatomic and pathologic relations of these vessels could be correlated with electrocardiographic and clinical observations. In 1962 angiographic visualization of numerous internal mammary-myocardial implants by direct injection of the internal mammary artery proved the validity of the operation. Since then, Effler and co-workers³ and other investigators^{2, 4, 5} advanced Vineberg's hypothesis, and attempts to improve the original concept have been numerous. This discussion is based on our experience with selection and surgical treatment of patients with angina pectoris.

CLINICAL MATERIAL

From June, 1964, to June, 1966, selective coronary angiography was performed on 160 patients with angina pectoris, 32 of whom were considered candidates for myocardial revascularization. Of these, 29 were men and 3 women, ranging in age from 30 to 72 years; excluding these two extremes and another patient 61 years of age, the remainder were in the fifth and sixth

Table 1. *Myocardial Revascularization*

PROCEDURE	NO. PATIENTS	HOSPITAL DEATHS
Internal mammary implant	18	0
Internal mammary implant and omental graft	10	0
Saphenous vein graft	2	0
Total revascularization	2	0
TOTAL	32	0

decades of life. One-third of the patients had had at least one attack of myocardial infarction. Various types of operations were performed to revascularize the myocardium; the type employed depended on the pathologic changes in the coronary arteries noted in the coronary angiogram and at operation (Table 1).

SELECTIVE CORONARY CINEANGIOGRAPHY

If clinical and electrocardiographic observations are suggestive of a diagnosis of angina pectoris, selective coronary angiography is indicated. Likewise, if the patient has a history of angina, but exercise electrocardiograms do not support the clinical observations, coronary angiography will provide information to prove or disprove whether the patient's pain is really angina.

With the development of adequate electronic equipment and perfection of the technique of selective coronary cineangiography, accurate delineation of arteriosclerotic disease of the major coronary vessels became possible. Catheterization of each coronary artery with single hand injection in at least three separate planes has added greatly to the ability to localize an obstructive or constrictive lesion of the coronary arteries. The advantages of selective catheterization of the coronary ostia over aortic root injection (even when temporary reduction or cessation of cardiac output is accomplished) are many. For one thing, there is no overlap of the three major vessels. Moreover, much better filling of the coronary vessels can be obtained than by aortic root injection. Also, the coronary arteries are studied under normal conditions with natural cardiac function and use of a much more physiologic preparation. And finally, usually only 7 to 8 cc. of contrast material for a single injection is needed for excellent visualization of the coronary arteries. Unfortunately, the equipment is expensive and technical skill is necessary to obtain consistently diagnostic films. We use a 9-inch image amplifier tube mounted so that it can be rotated all the way around the patient to obtain oblique and lateral views without moving him. The image is monitored on a television screen, and the cineangiograms are recorded on 16-mm. or 35-mm. film.

TECHNIQUE. An open-end catheter with side holes is inserted into the right brachial artery and advanced under fluoroscopic and electrocardiographic monitoring into the ascending aorta, and then selectively into each coronary artery, where 5 to 8 cc. of 70 per cent diatrizoate (Hypaque) is injected manually. The cineradiographs are usually made in the anteroposterior, right anterior oblique, and left anterior oblique views. The catheter is then passed across the aortic valve for measurement of end-diastolic pressure in the left ventricle, as well as for detection of aortic stenosis. The catheter is then changed for an angiographic catheter, and 50 cc. of 90 per cent Hypaque is injected into the aortic root.

TECHNICAL PROBLEMS. Coronary cineangiography appears to be safe if proper precautions are taken and adequate resuscitative equipment is available. Reactions to the different concentrations of contrast material used vary greatly. A 70 per cent iodine concentration is well tolerated and much less likely to result in serious reaction than a stronger contrast material.

Injection into the left coronary artery rarely produces difficulty. In our last 100 patients who had injection into the left coronary artery, 84 had no change in the heart rate, none had evidence of ST segment elevation or depression, and only 16 had evidence of arrhythmia. Multiple and multifocal ventricular premature beats occurred in 2 patients, sinus arrest with nodal escape in one patient, sinus arrest with ventricular escape in another patient, and single, isolated, ventricular, premature contractions occurred in the remainder. In regard to the electrocardiographic changes other than arrhythmias, standard lead II was employed as a baseline; injection into the left coronary artery resulted in a transient rise, averaging 10 seconds in the height of the T wave by 3 to 5 mm. in 67 per cent of patients. Changes in QRS voltage or ventricular conduction were noted in only 2 patients, in both of whom severe sinus bradycardia developed.

By contrast, injection into the right coronary artery results in frightening changes in the blood pressure and electrocardiographic tracing. Often, the blood pressure drops precipitously and transient periods of cardiac arrest develop. In our last 100 injections into the right coronary artery, the heart rate dropped from a mean of 86 to 34 immediately after the injection with a range from 74 to 7 per minute. In almost every patient sinus bradycardia developed. Only 20 per cent of the patients had no pronounced reduction in heart rate. The average duration of the reaction was 50 seconds. This is due partly to the bradycardia and poor "washout" of the diatrizoate. Various arrhythmias developed. These included nodal premature beats, atrial premature beats, nodal rhythm, sinus arrest, ventricular escape, multifocal ventricular premature beats, and brief bursts of ventricular tachycardia. Frequent changes in the intraventricular conduction with generally great increase in R voltage in standard lead II and in reduction in Q voltage were also noted. The QT interval tended to become prolonged in between 30 and 35 per cent of patients, and large positive U waves developed in 15 per cent of patients. ST segment depression was noted during injection in 14 per cent of patients. The maximum ST segment depression was 7 mm. with a mean of 3 mm. T wave inversion, bradycardia, and prolongation of the QT intervals, which were always self-limited, were the most remarkable changes. Resuscitative measures were not necessary, although whenever the reaction appeared to be prolonged, the catheter was immediately removed from the coronary ostia to enable maximum flow of blood down the coronary artery in an effort to wash out the contrast material. One instance of ventricular fibrillation occurred during recording of the left ventricular pressure, and the heart responded immediately to direct current

countershock. More recently, an episode of ventricular tachycardia of 20 seconds occurred during injection in the left coronary artery.

The right coronary artery is entered much more easily than the left. This appears to be due to the angle of exit of the coronary artery from the aorta, as well as to the approach of the catheter down the ascending aorta. If difficulty is encountered in entering the left coronary artery, usually satisfactory films may be obtained by placing the catheter in the left sinus of Valsalva.

The incidence of arrhythmia, bradycardia, or T wave inversion was no different in patients with normal or diseased coronary arteries. This fact must be attributed primarily to the dominant supply of blood of the right coronary arteries to the conduction tissues of the SA-AV node. Therefore, serious, transient reactions from injection into the right coronary artery are not considered to be evidence in themselves of disease.

TECHNIQUE OF REVASCULARIZATION

Immediately before induction of anesthesia with nitrous oxide, 50 per cent oxygen, and halothane, the patient is given 1/150 gr. of nitroglycerin sublingually. The cardiac function, as indicated by electrocardiography, and arterial pressure, as measured by direct arterial cannulation, are continuously monitored on an oscilloscope at induction of anesthesia and throughout the operation. During operation, 1/200 gr. of nitroglycerin is injected intramuscularly every 40 minutes to minimize coronary artery spasm. Because this drug may produce varying degrees of hypotension, a normotensive state is maintained by intravenous titration of a vasopressor substance. The patient is placed in a right lateral position and a generous left lateral thoracotomy incision is made. The left hemithorax is usually entered through the sixth intercostal space, although the interspace selected depends on which interspace traverses the apex of the heart as demonstrated in an erect postero-anterior roentgenogram of the chest. The pericardium is opened anterior to the left phrenic nerve and the coronary arteries are palpated. The severity of calcific deposits can be determined by correlation of the observations at operation with those in the coronary angiograms. The decision on type of operation best suited for the individual candidate is then made.

Internal Mammary-Myocardial Implant

The pericardial fat is grasped with large hemostats to retract the heart laterally and posteriorly; this maneuver brings into view the course of the internal mammary artery. The parietal pleura, fascia, and muscle overlying the internal mammary artery are incised, and the vessel is dissected from the second intercostal space to the sixth rib. The proximal intercostal

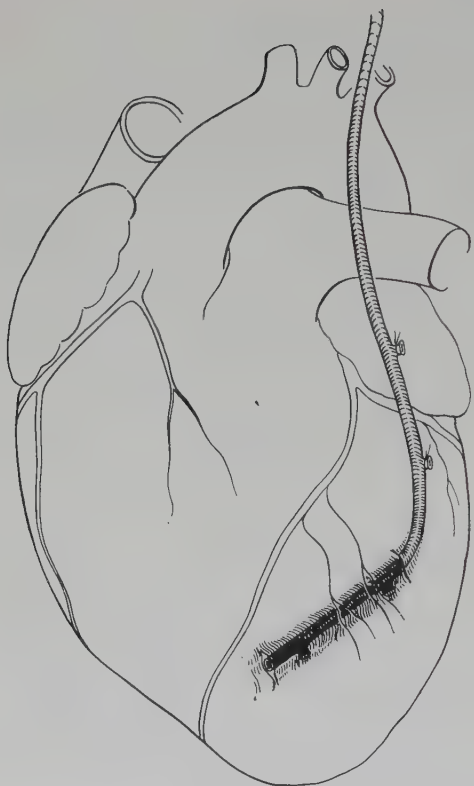


Figure 1. Diagram showing site of internal mammary-myocardial implant. The myocardial tunnel is placed beneath the diagonal branches of the anterior descending branch of the left coronary artery.

branches are ligated with 5-0 silk, and the distal two or three branches are dissected for a short distance from the internal mammary artery. Attention is then directed to the heart, where the pericardial fat is dissected from the pericardium and reflected medially. The cephalad-most portion of the pericardial fat is incised so as not to impinge on the internal mammary artery when this vessel is tunneled into the myocardium. A segment of the pericardium overlying the anterior surface of the left ventricle is excised. A site is selected for the myocardial tunnel, and the inferior end of the tunnel is created by a small myocardial incision with a No. 15 knife blade. The myocardial tunnel is developed with an Effler-Grove tunneling forceps and is so directed that the tunnel is positioned beneath diagonal branches of the anterior descending branch of the left coronary artery (Fig. 1). A suture is pulled through the tunnel, and the proximal end of the suture is tied to the distal end of the dissected internal mammary artery. The artery is then freed from the thoracic wall by severing the remaining distal intercostal branches and dividing the internal mammary at the sixth rib. The branches are allowed to bleed freely while the artery is pulled within the myocardial tunnel. A purse-string suture is placed around the distal end of the myocardial tunnel to close the opening, and the same suture is tied to the

suture used to pull the artery into the tunnel. This fixes the artery within the myocardial tunnel.

Free Omental Graft

An incision long enough to accommodate introduction of the hand is made in the dome of the left diaphragm. The apron of the omentum is grasped and delivered into the chest. A large portion of the omentum, 25 by 15 cm., is excised and allowed to remain free in the posterior sulcus of the left pleural cavity while epicardiectomy is performed. The trauma of scraping the epicardium and serous surface of the pericardium produces transient arrhythmias. The myocardial irritability is lessened by intravenous administration of lidocaine; 40 mg. is administered at the commencement of epicardiectomy and the injection is repeated at intervals as needed. We prefer to administer no more than 120 mg. during the operation.

The epicardium should be removed from both the right and left ventricular surface with Vineberg scrapers. As much epicardium as possible should be removed between the coronary vessels. Care should be exercised not to injure these vessels. All ventricular surfaces should be scraped until there is diffuse oozing of blood from the denuded surface. The periaortic areolar tissue should be scraped from the ascending aorta. After complete epicardiectomy, the serous surface of the pericardium should be removed. We have found the coarse Beck rasps to be most suitable for this maneuver. Care must be taken not to injure the phrenic nerve. An effort should be made to remove the entire serosal lining of the pericardium. The heart must be permitted to rest for short intervals if arrhythmia occurs. After epicardiectomy and removal of the serous surface of the pericardium, the free omental graft should be placed around the heart and onto the ascending aorta. It should be sutured in place to maintain its position and not to interfere with the function of the internal mammary implant.

Autogenous Vein Graft

Revascularization of the posterior aspect of the left ventricle is attempted by grafting an autogenous vein onto the descending thoracic aorta and then implanting this graft into the posterior myocardium (Fig. 2). A 10-cm. segment of greater saphenous vein with two or three tributaries is removed from the mid thigh. The distal end of the vein is anastomosed to the distal descending thoracic aorta excluded by a partial occlusion clamp. The proximal end with the freely bleeding tributaries is then tunneled into the posterior wall of the left ventricle in the same manner as one performs an internal mammary implant.

When two or more of the foregoing surgical maneuvers are performed first, the internal mammary artery is dissected free in its bed. Then the omentum is obtained for its free graft. During this period, the saphenous vein can be obtained from the right mid thigh and the aorta prepared for grafting this vein. We prefer then to perform the epicardiectomy and

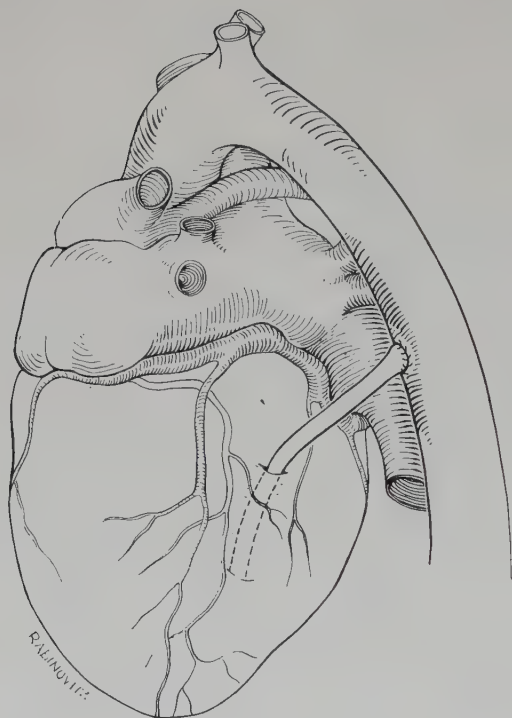


Figure 2. Diagram illustrating method of revascularization of posterior aspect of heart. An autogenous saphenous vein is grafted to the descending thoracic aorta and tunneled into the posterior portion of the left ventricular wall.

removal of the serous surface of the pericardium. It is important to place the omentum in its position and tack it posteriorly and inferiorly. This should be done before tunneling of the internal mammary artery or the autogenous vein graft, for placement of the omental graft often elevates the heart and redundancy of the implant will exist if the implant is performed first. The posterior saphenous vein graft is then performed. Lastly, the internal mammary artery is implanted into the anterior wall of the left ventricle. The rest of the omentum is then tacked around the implants in such a manner as not to hinder the function of either the posterior or anterior implant.

RESULTS

During the past 18 months, myocardial revascularization was performed on 32 patients. In the early months, only patients with occlusive disease limited to the anterior descending branch of the left coronary artery were considered for operation. Subsequently, we extended the operative indications by addition of supplementary procedures to enhance extra-coronary blood supply to other segments of the heart besides the anterior wall of the left ventricle.

In 18 patients, an internal mammary-myocardial implant was used to revascularize the anterior wall of the left ventricle. A free omental graft supplemented a similar implant in another 10 patients who had associated occlusive disease in the right coronary artery, the circumflex branch of the left coronary artery, or both. Two patients with isolated, pronounced narrowing of the distal circumflex artery had an autogenous vein grafted off the descending thoracic aorta and tunneled into the posterior myocardium of the left ventricle. In 2 patients with triple artery disease, total myocardial revascularization was attempted by an internal mammary-myocardial implant into the anterior wall of the left ventricle, a free omental graft, and an autogenous vein graft implanted into the posterior wall of the left ventricle.

There were no hospital deaths among our 32 patients, although one patient died shortly after discharge from the hospital. Necropsy showed the internal mammary-myocardial implant to be open (Fig. 3). Since it takes time for the implanted internal mammary artery to form arterioles which join with the myocardial coronary arteries, the myocardium does not receive sufficient protection for two or three months. All patients except one have shown clinical improvement since operation. The one exception is a patient who had congestive heart failure at the time of operation and

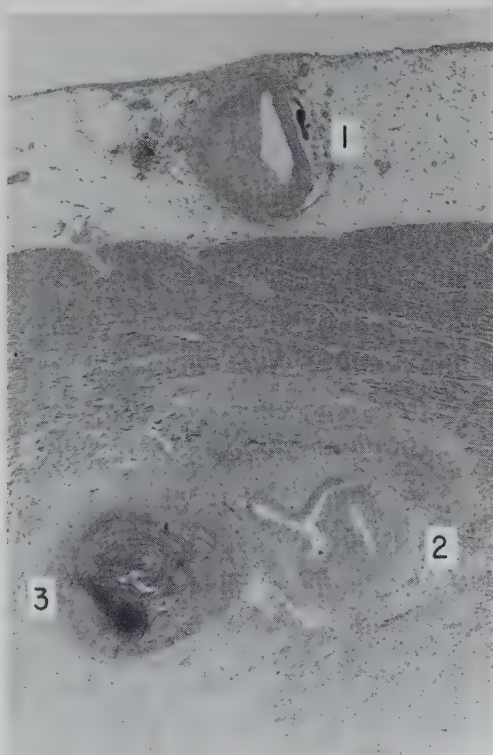


Figure 3. Photomicrograph of ventricle with internal mammary-myocardial implant. 1. Branch coronary artery within subepicardial adipose tissue and showing arteriosclerotic intimal plaque. 2. Left internal mammary artery implanted within myocardium. Note patent branch leading from lumen of internal mammary artery. 3. Area of hemorrhage in myocardial tunnel from internal mammary implant.

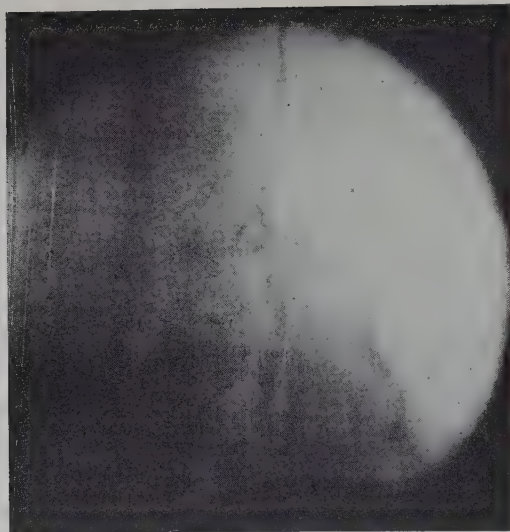


Figure 4. Frame from cine internal mammary angiogram showing course of internal mammary one year after internal mammary-myocardial implant.

continues to show evidence of left ventricular failure eight months after operation. Of 20 patients operated on six months ago or longer, all except the one just mentioned are greatly improved. Twelve patients claim complete freedom from anginal pain. The remaining 7 state that the amount of pain has diminished and that pain occurs only after moderate to maximum exertion. Our plan is to study each patient one year or more after operation by direct injection of the internal mammary artery or saphenous vein implant. We have studied only 3 patients in this way, each with an internal mammary-myocardial implant. In all 3 the implant was found to be open and the contrast medium was seen to opacify the left anterior descending and marginal arteries with a subsequent intense "myocardial blush" indicating excellent left ventricular flow (Fig. 4). Although these results represent only our early operations, the clinical improvement of most patients plus the angiographic demonstration of revascularization in the early cases has encouraged us greatly.

DISCUSSION

Now that unequivocal evidence is present that surgical revascularization of the myocardium is possible, all physicians treating patients with angina pectoris must at least give thought to the possibility that a particular patient may be benefited by one of the surgical procedures now available. Any patient considered a candidate for myocardial revascularization must have coronary cineangiography. Selective coronary cineangiography is far superior to other methods. Aortic root injection should be performed only if the coronary ostia cannot be successfully catheterized.

The diagnosis of angina pectoris still rests entirely on clinical grounds.

Coronary cineangiography is used to select patients whose condition may be amenable to myocardial revascularization. To this end certain criteria have been established.

1. It is presumed that total obstruction of a coronary artery with electrocardiographic evidence of old transmural myocardial infarction in the same area is not a contraindication to the revascularization procedure, since it is unlikely that the angina pectoris is arising in this area.

2. Since laboratory studies and previous clinical experience suggest that rather severe narrowing of a coronary vessel must be present before internal mammary transplants will be of permanent benefit to the patient, we have insisted on demonstration of 70 per cent narrowing of one of the major vessels of the coronary artery in the left coronary circulation.

3. At present there is question of the efficacy of surgical treatment for diffuse narrowing or disease of the right coronary artery, although in those patients undergoing internal mammary transplants for disease of the left coronary artery, a free omental graft is also done in the hope that this will be of benefit.

4. The ideal situation would appear to be narrowing of the anterior descending or left marginal branch of the left coronary artery, although proximal partial obstruction of the circumflex branch may also respond well to an internal mammary transplant.

5. Demonstration of well developed collateral circulation between the right and the left, or vice versa, has to date been considered a contraindication against the addition of an internal mammary transplant, although this view at present is being reconsidered.

6. In certain instances, it has been deemed advisable to attempt revascularization of the posterior surface of the left ventricle in the presence of distal left circumflex disease.

7. Demonstration of severe ostial stenosis would appear to be an indication for direct surgical attack on the coronary artery, although this condition appears to be extremely rare.

Since the report of Effler and co-workers of a large series of patients treated successfully by Vineberg's operation, many have added various surgical maneuvers in an attempt to improve the original procedure or extend the indications for operation. New operations must be carefully studied, both experimentally and clinically, before their efficacy can be determined.

The medical profession was slow to accept Vineberg's operation. During this period, surgery of the coronary arteries was also not looked upon with favor. Much of this was due to the fact that many operations proposed for improvement of myocardial circulation were unphysiologic or had not been studied experimentally. Precious years have been wasted for those with occlusive coronary artery disease, but we must not accept procedures until their value has been proved. If we do, we jeopardize the high status which

proved operations, such as the internal mammary-myocardial implant, now enjoy.

SUMMARY

Myocardial revascularization has become a reality. Selective coronary cineangiography has enabled precise anatomic delineation of coronary artery disease so that candidates for myocardial revascularization can be recognized. Internal mammary-myocardial implantation is a proved method supplying extracoronary blood to the myocardium. Other surgical techniques have been proposed recently to supplement the internal mammary-myocardial implant, but their value has not yet been established. During the past two years 160 patients in our Clinic have undergone selective coronary cineangiography to study the coronary arteries. Thirty-two were selected for myocardial revascularization; 18 had internal mammary implant, 10 internal mammary implant and omental graft, 2 saphenous vein graft and 2 total revascularization. There were no hospital deaths, although one patient died after discharge. All except one have shown clinical improvement since operation.

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Cardiac Surgery in Infancy

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Approximately 20,000 babies with cardiac defects are born annually in the United States.¹⁶ Despite available diagnostic and therapeutic methods, 10,000 children die annually from diseases of the heart and great vessels.¹⁰ As two-thirds of these deaths occur in infancy, they are related primarily to congenital defects; therefore, specific attention should be directed toward care of the infant if these high mortality figures are to be reduced.

Unlike acquired heart disease, structural congenital cardiac defects are uniquely amenable to surgical correction or palliation. Surgical techniques have been developed which enable complete cure or lifesaving improvement for all except infants with rare complicated cardiac malformations. The success of these surgical procedures in infants has been attested by reported survival rates of 60 to 89 per cent.^{5, 9, 12, 15}

Among the more common congenital cardiac malformations which threaten the infant's life are patent ductus arteriosus, tetralogy of Fallot, transposition of the great vessels, ventricular septal defects, coarctation, tricuspid atresia, and pulmonary stenosis. Since 1939, when Gross⁷ successfully corrected a patent ductus arteriosus, surgical correction or palliation of numerous other cardiac defects has been accomplished. Even in more complicated anomalies, such as truncus arteriosus, total anomalous pulmonary venous return, and atrioventricularis communis, surgical manipulation has resulted in cure or improvement.

To state, however, that proper management of infants with cardiac distress is exclusively surgical is unsound. To recommend medical management with surgical treatment as a last resort is equally unwise. Fundamental to selection of appropriate management is an accurate anatomic-physiologic diagnosis, knowledge of the natural history of the defect, assessment of its effect on the individual patient, and realization of the surgical versus medical risk.

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DIAGNOSIS AND GENERAL MANAGEMENT

Diagnosis of the exact anatomic-physiologic cardiac abnormality is essential for successful treatment.⁹ Although a classification can be made from information obtained by physical examination, electrocardiography, and roentgenography, accurate diagnosis usually requires cardiac catheterization and angiocardiology. These procedures should be performed on every infant with cardiac distress. Reluctance to perform them in the past was based on the high mortality and morbidity rates. This is no longer tenable, as evidenced by the experience of others as well as our own with 103 infants 2 years of age or younger (the youngest being 4 hours old and the smallest 4 pounds) in whom no deaths and no important morbidity could be attributed to the procedure.⁹

Use of image intensification fluoroscopy, cineangiocardiology, determinations of intracardiac and extracardiac pressures and blood oxygen saturations, dye dilutional studies, and blood gas studies have yielded unerring results in the diagnosis of the anatomic-physiologic disturbances in these infants. Physicians caring for infants with cardiac distress should be prepared to perform all of these studies, and on short notice, since in the neonate a matter of hours may determine success or failure of treatment.

Once an accurate diagnosis has been established, a decision should be made regarding medical or surgical treatment. If surgical management is selected, the infant should be immediately prepared for operation. Adequate hydration and correction of acidosis are essential, especially in the anoxic infant, who frequently has uncompensated metabolic acidosis.⁶ The infant with congestive heart failure should be rapidly digitalized. Administration of antibiotics should be started because mild infection often precipitates heart failure.

Surgical treatment should not be unduly delayed to observe the infant in the hope that improvement will occur. In the infant with unresponsive congestive heart failure or severe anoxemia, an irreversible state may be reached within hours. Frequently, these infants must be taken directly from the catheterization laboratory to the operating room.

The method of anesthetization should be individualized; however, after complete atropinization, an anesthetic mixture containing a high concentration of oxygen (usually 0.5 to 1.0 per cent halothane) and supplemented by a muscle relaxant, has proved the most successful for us. The cardiac rhythm, systemic blood pressure, and temperature should be carefully monitored throughout the operation. The temperature is extremely important, since hypothermia is a much greater problem in infants than in older children. Normal body temperature has been maintained by a water-circulating plastic mattress, which is thermatically controlled.

Although extracorporeal circulation has been used successfully,² a palliative closed heart procedure should be used whenever feasible, because it will result in the highest survival rate. Staged operations for correction

of certain congenital anomalies has proved safer than total correction in one stage with the inherent dangers of extracorporeal circulation in the newborn and infant. Some defects, however, are not amenable to surgical palliation, and extracorporeal circulation is necessary for correction. Here, it is important to miniaturize all components of the extracorporeal apparatus and to use whole blood as the circulating medium.

CLINICAL EXPERIENCE

From 1961 through 1965 surgical treatment was employed for congenital malformations of the heart and great vessels in 90 infants younger than 2 years of age at the Ochsner Clinic (Table 1). The youngest was 12 hours old. The smallest weighed 4 pounds, and the largest 24 pounds.

Patent Ductus Arteriosus

Patent ductus arteriosus is the most common congenital cardiac malformation corrected during infancy. The operation may be an elective or emergency procedure. Although many infants with this condition could be managed medically, the surgical risk is minimal. We, therefore, usually recommend surgical treatment in all infants with patent ductus arteriosus who have congestive heart failure or cardiomegaly, regardless of their response to medical therapy.

Patent ductus arteriosus can usually be diagnosed clinically, a late systolic or machine-like murmur and increased amplitude of the peripheral arterial pulses being the most distinguishing clinical features. At times the clinical signs may be atypical, and cardiac catheterization indicates its presence. Cardiac catheterization is performed to confirm the diagnosis of patent ductus arteriosus and to determine the pulmonary arterial pressure and the presence of associated anomalies, such as ventricular septal defects

Table 1. *Survival Rate in 90 Infants with Congenital Cardiac Anomalies Treated Surgically*

MALFORMATION	NUMBER OF PATIENTS	SURVIVORS
Patent ductus arteriosus	22	22
Tetralogy of Fallot	22	20
Ventricular septal defect	10	10
Transposition of great vessels	9	6
Tricuspid atresia	6	6
Coarctation of aorta	4	3
Pulmonary stenosis	4	4
Miscellaneous	13	7
TOTAL	90	78(87%)

or stenosis of the pulmonary artery, the latter being extremely common in the rubella-affected infant.

Surgical obliteration or division of a patent ductus was employed in 22 patients. The ductus was divided and sutured with the Potts ductus clamps in 10 patients, and in 12 it was ligated without division. Not many years ago simple ligation of a patent ductus arteriosus was condemned because occasional recannulization followed such a maneuver. However, in yesteryear, umbilical tape or thick suture was used to obliterate the ductus. Because of the inability to completely tie down such thick material plus the stretching of umbilical tape, which is a woven cotton fabric, often the lumen did not remain obliterated. Today, with better suture material swedged onto a needle, the chances of reopening of the ductus after ligation seem inconceivable. Ligation without division of a patent ductus arteriosus can be performed quicker than division and suture of this structure. Time is essential to survival in a critically ill baby with congestive heart failure. The ductus should be ligated triply, beginning first on the aortic wall adjacent to the ductus. The sutures should be passed only through the adventitia of the ductal-vessel junction in two or three locations and should not puncture the lumen. The middle ligature is placed as a simple ligature without suture. Today, it appears that the only advantage of division and suture of a ductus over ligation is the fact that some insurance companies give preference to the person who has had division and suture of a patent ductus³ in contrast to one having had simple ligation. When the long-term results of ligation of a ductus, as practiced today, are determined, however, the discrepancy undoubtedly will no longer exist.

There were no deaths in this series of 22 infants. With adequate precautions the mortality rate should remain minimal for surgical correction of this condition.

Tetralogy of Fallot

Tetralogy of Fallot is the most common cause of cyanotic heart disease regardless of age. In the neonate, it rarely produces cardiac distress, but as cardiac demand increases with age, the infant becomes symptomatic. The mere presence of cyanosis is insufficient indication for surgical treatment. In infants with tetralogy of Fallot who are having paroxysmal anoxic spells or profound anoxemia, which interferes with normal growth and psychomotor development, surgical intervention is indicated.

The clinical features of tetralogy of Fallot are usually sufficiently distinctive to indicate a clinical diagnosis. Cine-angiocardiology and modified cardiac catheterization are performed to determine systemic blood oxygen saturation and blood gas tensions, and to perform selective right ventricular angiocardiology for visualization of the right ventricular outflow tract, pulmonary arteries, aorta, and great vessels of the arch.

Surgical palliation has enabled these infants to grow to an age at which

complete correction can be accomplished with minimal risk. In this series, 22 infants with tetralogy of Fallot underwent systemic-pulmonary artery anastomosis to increase pulmonary blood flow. Twenty (91 per cent) of these are alive, and each has shown clinical improvement from the shunt.

The two deaths were due to prolonged anoxemia with resultant cerebral edema. The anastomosis must be accomplished quickly, and during its performance maximum oxygenation must be assured. In one patient subclavian-pulmonary artery anastomosis was unsuccessful and aortopulmonary artery anastomosis was subsequently performed the same day. It is our policy to perform subclavian-pulmonary artery anastomosis when feasible. Experience has shown that such an anastomosis can be taken down without difficulty at the time of total correction, whereas obliteration of an aortopulmonary artery anastomosis is formidable and not without risk. The use of 6-0 interrupted sutures and a magnifying loupe have aided in performance of these small anastomoses. If the patient weighs less than 10 pounds, aortopulmonary anastomosis is more expedient and safer. Angiocardiography has provided useful information for planning the type of systemic-pulmonary shunt by visualizing the anatomic relations of the aortic arch and its branches. In patients whose innominate artery appears long with a short subclavian component, difficulty may be encountered in obtaining adequate length of the subclavian artery and thereby tension at the anastomosis. In contrast, if the innominate artery is short, the ipsilateral subclavian artery usually will be long enough for proper anastomosis. In our series, 14 patients underwent subclavian-pulmonary artery anastomosis and 8 had aortopulmonary artery anastomosis.

Ventricular Septal Defect

The rapidly changing concepts of the natural history of infants with ventricular septal defects, especially the indication that reduction in size and possibly even spontaneous closure may occur, suggest that aggressive medical management is the most logical treatment. Surgical intervention appears to be necessary only if the infant manifests profound failure to thrive, repeated episodes of pneumonia, and uncontrollable heart failure. Total surgical correction of the defect in infancy has been advocated.² The obviously increased surgical risk of total correction, however, as contrasted with palliative pulmonary artery banding, signifies that the latter is the correct approach.

Ten infants with ventricular septal defects in our series continued to have congestive heart failure despite medical therapy so that surgical decrease of pulmonary blood flow became necessary. Placement of a constricting band around the pulmonary artery results in control of pulmonary blood flow. A woven Teflon tape, 1 cm. wide, is placed around the main pulmonary artery (Fig. 1). Initially, we attempted to determine the degree of desirable constriction by simultaneous measurement of the right ventricle, pulmonary artery, and aortic pressures, and constricting the pulmonary

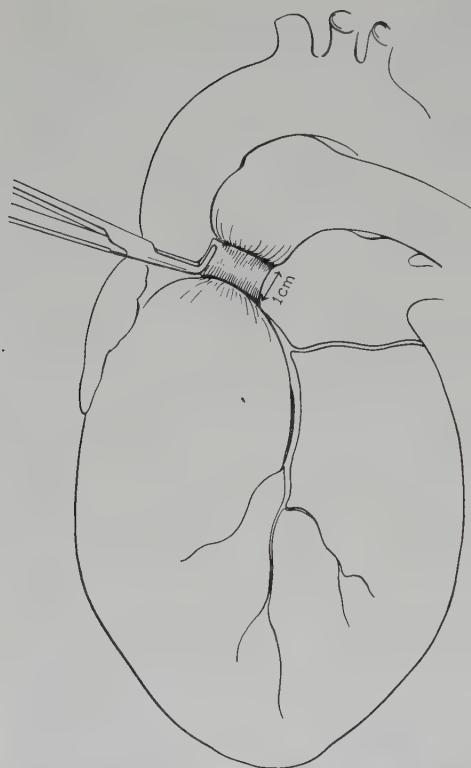


Figure 1. Technique of pulmonary banding. A right-angled hemostat holds 1 cm. Teflon tape, which constricts main pulmonary artery. Once desired constriction is obtained, the ends of the tape are sutured to maintain constriction.

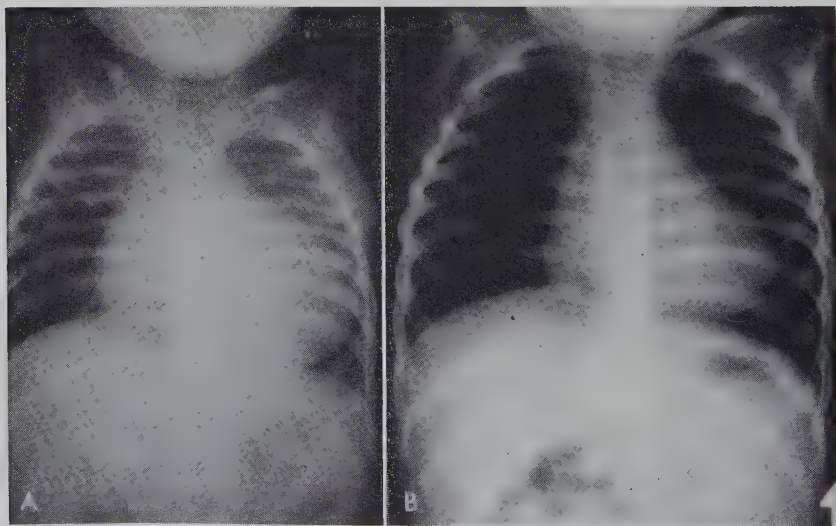


Figure 2. Postero-anterior roentgenograms of chest. *A*. One-month-old infant with large ventricular septal defect and severe congestive heart failure despite medical treatment. *B*. Same child two months after banding of pulmonary artery. Heart has decreased in size and pulmonary fields are clear.

artery to a point where the pulmonary artery pressure was one-half the right ventricular pressure or one-fourth the systemic pressure. Often, it was difficult to interpret these values because of the constant change in pressure and cardiac output during manipulation of the heart and great vessels in these critically ill infants. Palpation of the degree of thrill produced by the constricting band, the tension of the pulmonary artery, and visualization of the color of the left atrial appendage are usually sufficient to determine clinically the proper amount of constriction. This simple surgical maneuver provides immediate and prolonged benefit, which enables the infant to grow to a size more suitable for extracorporeal circulation necessary for complete correction of this condition (Fig. 2). There were no deaths among the 10 infants in our series who had banding of the pulmonary artery.

TRANSPOSITION OF THE GREAT VESSELS

Transposition of the great vessels offers, perhaps, the greatest challenge in pediatric cardiac surgery. It ranks as the fourth most common congenital cardiac defect after patent ductus arteriosus, ventricular septal defects, and tetralogy of Fallot, and among these four it has the highest mortality rate. Approximately 90 per cent of infants with transposition will die during the first year of life if untreated.¹⁴

Since the condition is surgically correctable in the older child, every effort should be made to get the patient through the crucial stage of infancy.¹⁰ Medical management has little to offer. Although the diagnosis can usually be suspected from the information obtained from physical examination, the exact status of the anatomic-physiologic disturbance must be determined by cardiac catheterization and angiocardiography. The mortality rate is directly related to the degree of mixing between the two parallel circuits and the degree of pulmonary hypertension. In infants with severe anoxemia and inadequate mixing, atrioseptectomy is recommended. If the infant has associated pulmonary hypertension, pulmonary artery banding is concomitantly performed. With adequate mixing and pulmonary hypertension, banding alone is done. In the occasional patient with inadequate mixing and severe pulmonary stenosis, combined atrioseptectomy and systemic pulmonary artery anastomosis may be beneficial.

Of 9 infants with transposition of the great vessels surgically treated by us, 6 are living. In 7 infants an atrial septal defect was created by a modification of the Blalock-Hanlon operation.¹⁴ In the other 2, besides atrioseptectomy, the pulmonary artery was banded. Early in our series, despite the atrioseptectomy, 2 infants with associated pulmonary hypertension died in the first 24 hours postoperatively as the result of pulmonary insufficiency. Since then, when pulmonary arterial pressure is equal to systemic pressure, we have banded the pulmonary artery at the time of atrioseptectomy. Total correction as described by Mustard¹² is postponed

until the child is larger and able to withstand extracorporeal circulation with less risk. The previous atrioseptectomy does not impose any technical difficulties at the time of total correction. One patient in our series has subsequently undergone successful total correction.

Tricuspid Atresia

This anomaly is the third most common cyanotic, congenital heart defect. The pulmonary blood flow may be increased or decreased, depending on the degree of pulmonary obstruction. Obstruction is usually severe, and the difficulty is due primarily to anoxemia or anoxic spells similar to those associated with tetralogy of Fallot. The distinguishing characteristic of this defect is cyanosis with evidence of left ventricular hypertrophy.

Medical treatment has no effect on the symptoms. Of the various surgical means to increase pulmonary blood flow, the superior vena cava-right pulmonary artery anastomosis has proved the most physiologic, and since no totally corrective procedure is known, one need not be concerned about the consequences of this operation on total correction at a later date. On the other hand, aortopulmonary artery anastomosis is more likely to function in the newborn and small infant, and since palliation is the goal, the Potts procedure provides such relief. Of the 6 patients in this group, 5 had aortopulmonary artery anastomosis and one had superior vena cava-right pulmonary artery anastomosis. In one child aortopulmonary anastomosis failed to provide adequate pulmonary flow as the child grew older, and four years later superior vena cava-right pulmonary artery anastomosis was necessary.

Coarctation of the Aorta

Controversy continues concerning selection of proper therapy for infants with coarctation of the aorta.¹ Reported survival rates of medical therapy alone range from less than 4 per cent³ to 90 per cent.¹³ Based on the lower figures, many advocate surgical treatment of the infant with coarctation of the aorta and cardiac distress. Selection of proper treatment depends on complete assessment of the individual patient.

The mortality rate is highest in infants with coarctation who have pulmonary hypertension and associated defects, such as patent ductus arteriosus or ventricular septal defects.¹ Coarctation can be easily diagnosed simply by recording blood pressures in the arms and legs. Cardiac catheterization and angiocardiography should, however, always be performed to determine pulmonary arterial pressure and the presence and severity of an associated cardiac lesion.

In infants with systemic pulmonary arterial pressure and associated defects, surgical treatment is advocated. Isolated coarctation without systemic pulmonary arterial pressure can be successfully treated by medical means. Surgical correction, thereby, can be delayed to an older age (Fig. 3).

Four infants with coarctation of the aorta had concomitant pulmonary

hypertension. In 2 a ventricular-septal defect or patent ductus arteriosus was associated with the coarctation. In all 4 patients coarctation was located in the postductal or justaductal position. In resection of the coarctated segment, patent ductus arteriosus is ligated by necessity. If the pulmonary arterial pressure remains excessively high owing to a ventricular septal defect after resection of the coarctated segment, the pulmonary artery is banded. Controversy still exists regarding growth of an aortic anastomosis made during infancy. It is, therefore, particularly important to obtain as wide an anastomosis as possible, and to insure this an incision is made along the left subclavian artery to enlarge the proximal lumen which ordinarily limits the size of the anastomosis (Fig. 4). To enhance the opportunity of growth of the anastomosis at least one-half of the anastomosis is made with interrupted sutures.

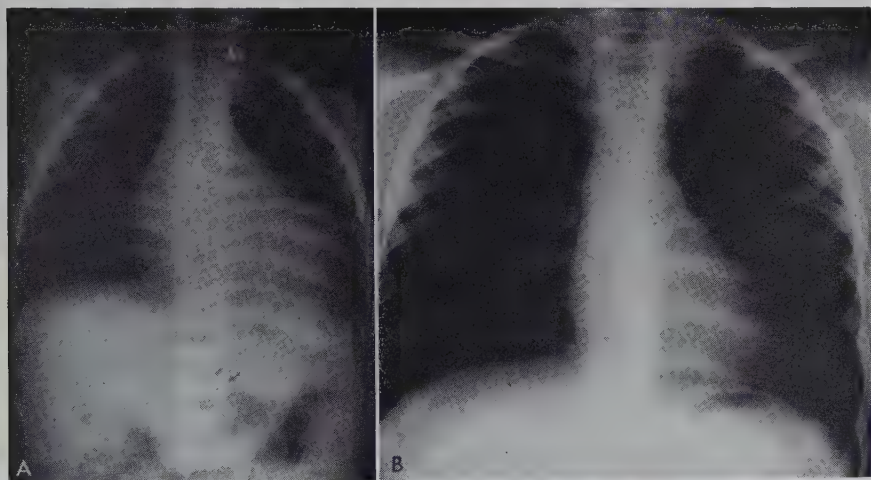


Figure 3. Postero-anterior roentgenograms of chest. *A.* Two-month-old baby boy with coarctation of the aorta and congestive heart failure treated medically. *B.* Four years later, patient is asymptomatic without medication and is awaiting elective surgical correction.

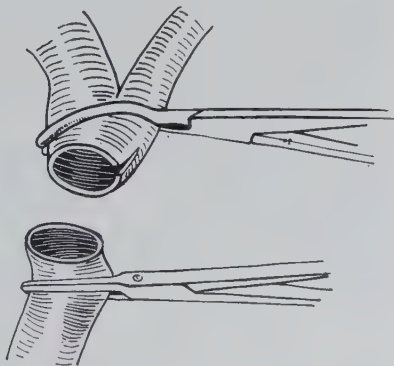


Figure 4. Technique of aortic anastomosis after excision of coarctated segment. The lumen of the proximal aorta is enlarged by an incision along the subclavian artery.

Pulmonary Stenosis

Pulmonary stenosis may be valvular, infundibular, or a combination of these. It may be the only anomaly or associated with a ventricular septal defect. The natural course of pulmonary stenosis depends on the severity of the malformation and the presence of an atrial communication. The obstruction produced by pulmonary stenosis usually is not severe enough to cause symptoms during infancy; however, severe pulmonary stenosis in the presence of an intact ventricular septum may prove fatal.

Pulmonary stenosis can be diagnosed by clinical observation, but cardiac catheterization provides information of the precise severity of the malformation. Right ventricular pressure greater than 100 mm. of mercury and electrocardiographic evidence of right ventricular strain are indications for early operation. If cyanosis or congestive heart failure becomes apparent during infancy, a fulminating course usually ensues and may shortly terminate in death. When pulmonary stenosis and an intact ventricular septum produce symptoms during infancy, the stenosis is uniformly valvular. Distinct commissures do not exist in the valve, which resembles a cone with a small opening at the apex. Surgical treatment is directed toward relief of the valvular obstruction by excision or incision of the valvular tissue. Since formed commissures are not present, one cannot be concerned about valvular competency during valvulotomy. In small infants we have noted that blind transventricular valvulotomy with dilatation is limiting, and therefore prefer open valvulotomy through the pulmonary artery with inflow vena caval occlusion. In large infants retrograde excision of small segments of the pulmonary valve cone with a Himmelstein valvulotome adequately relieves the obstruction. The valvulotome is manipulated through a transventricular incision with minimal risk. Four infants in our series had pure pulmonary valvular stenosis which was surgically corrected. Three were treated by transventricular pulmonary valvulotomy, and direct vision valvulotomy, utilizing vena caval occlusion, was employed in one patient. There were no deaths and all were asymptomatic postoperatively.

Miscellaneous

Many less common congenital cardiac anomalies may cause cardiac distress during infancy. Successful surgical correction is possible in some whereas in others only palliation is likely. In our series 2 patients each had aortic valvular stenosis, atrioventricularis communis, truncus arteriosus, and a vascular ring. Aortic stenosis requires extracorporeal circulation for correction, and there is no palliative operation of lesser magnitude. It is important not to make the valve incompetent during performance of valvulotomy, and consequently, the existing commissures should not be incised all the way to the aortic annulus. Minor residual pressure gradient may remain after the commissurotomy, but this will not be significant hemodynamically. One of our 2 patients with aortic stenosis died after operation, and necropsy proved concomitant mitral stenosis which was

probably the cause of death. Infants with atrioventricularis communis and truncus arteriosus have congestive heart failure due to excessive pulmonary blood flow and pulmonary hypertension. Reduction of blood flow by banding the pulmonary artery, as in patients with ventricular septal defects, has proved palliative. Infants with atrioventricularis communis, however, may not respond as well symptomatically to the banding procedure as those with ventricular septal defects. Both infants in our series with the truncus arteriosus defect had Type I, and banding of the main pulmonary trunk was possible. A double aortic arch and a right aortic arch with a left ligamentum arteriosum were the anatomic variants of vascular ring found in this series. Concomitant constriction of the trachea and esophagus can be demonstrated by simultaneous performance of tracheography and esophagography (Fig. 5). Only surgical interruption of the constricting vascular ring can relieve symptoms. The lesser important limb of the vascular ring is divided and separated.

Single instances of other malformations encountered by us include: single ventricle with pulmonary atresia, total anomalous pulmonary venous return, Ebstein's malformation, anomalous systemic venous return, and multiple pulmonary aneurysms. The availability of various operations and an understanding of the exact anatomic-physiologic disturbances in these complicated defects has led to surgical palliation or correction in many. Undoubtedly, the operative mortality rate is higher in these infants, some of whom harbor incorrectible malformations.

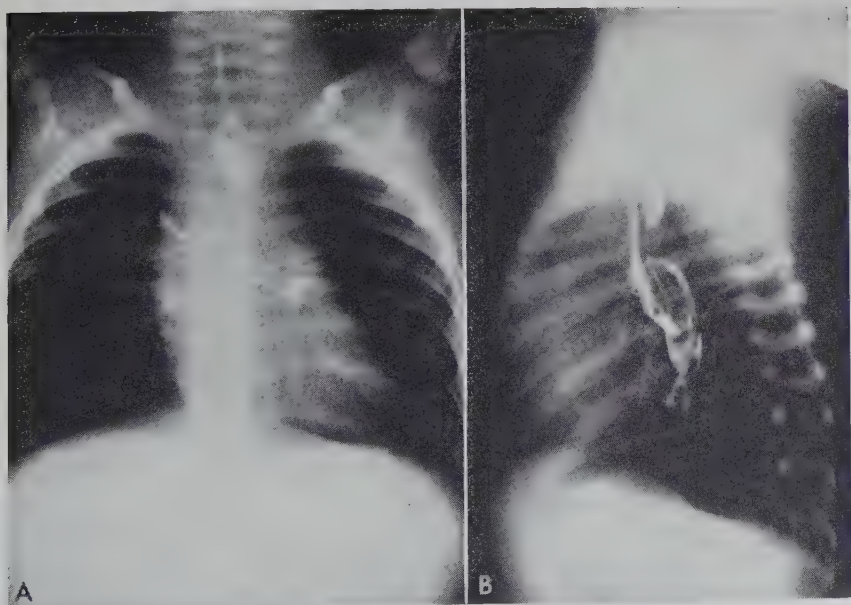


Figure 5. Simultaneous esophagram (A) and tracheogram (B) showing obstruction of esophagus and diffuse compression of trachea caused by a right aortic arch with a left ligamentum arteriosum. Incidental finding is trifurcation of trachea.

POSTOPERATIVE CARE

Often, in these critically ill infants, success or failure is the result of the immediate postoperative care.⁸ Homeostasis in an infant is so delicate that any imbalance may produce irreversible damage. Therefore, strict attention must be paid to every aspect, no matter how small, in the resuscitation and convalescence of these babies. After resuscitation, normal body functions should be maintained, and efforts should be directed toward prevention of complications. Of special importance is support of normothermia and adequate pulmonary ventilation. The latter is perhaps the most common cause of death in infants after cardiac operations. Ventilatory assistance via an endotracheal tube with manual or delicate mechanical control is often necessary for the first 24 to 48 hours postoperatively. Frequent determinations of the blood gases and pH, and amelioration of their alterations are essential. Collecting receptacles for body fluid losses must be miniaturized and labeled so that increments as small as 5 cc. can be measured and replaced. Frequent microdeterminations of electrolytes to insure normal balance is necessary.

SUMMARY

Aggressive clinical effort toward early and exact diagnosis of congenital heart disease in the infant is of foremost importance. Medical and surgical management are of equal importance. Fundamental to selection of one or the other is knowledge of the natural history of each defect, its effect on the individual patient, the surgical and medical risks, and the results.

Extracorporeal circulation can be performed in children with minimal risk; however, infants younger than one year of age have less tolerance to this procedure. Therefore, in cases in which palliative procedures can be performed and extracorporeal circulation delayed to a later date, such a course will result in a higher survival rate of these sick infants.

Many cardiac anomalies can be totally corrected during infancy without the use of extracorporeal circulation. These include patent ductus arteriosus, coarctation of the aorta, vascular ring, and pulmonary valvular stenosis. It is necessary to employ extracorporeal circulation to correct aortic stenosis and total anomalous pulmonary venous return, which are symptomatic during infancy, and the hazards of extracorporeal circulation should not deter one from prompt surgical correction if it is desirable. Tetralogy of Fallot, ventricular septal defect, atrioventricularis communis, and transposition of the great vessels are best treated by staged operations, that is, a palliative, closed-heart operation during infancy and complete correction utilizing extracorporeal circulation at a later date. Tricuspid atresia is the only common congenital cardiac anomaly for which there is no totally corrective operation, but these infants can be improved by systemic pulmonary artery shunt.

With refinement and miniaturization of extracorporeal apparatus, many of the defects being corrected by staged operations today may some day undergo complete correction at a single operation. However, until such apparatus can be perfected, the course which yields the best result must be followed. An aggressive, combined medical-surgical approach to the care of infants with congenital heart disease can prevent many unnecessary deaths.

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